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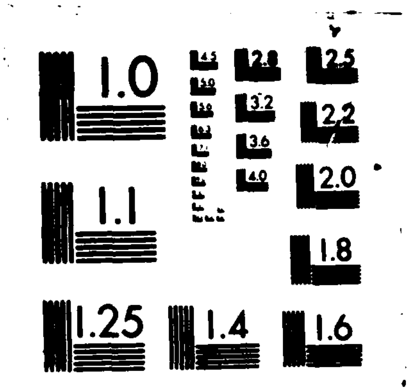

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Results of Loran C Nonprecision Approach Flight Checks for the Limited Implementation Program

Robert H. Erikson

May 1987

DOT/FAA/CT-TN86/62

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U.S. Department of Transportation
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16. Abstract

This report describes flight tests conducted by the Federal Aviation Administration (FAA) Technical Center at nine airports across the continental United States. The airports were selected for the joint FAA/National Association of State. Aviation Officials (NASAO) limited Loran C implementation program for instrument flight rules nonprecision approaches. Flight inspection procedures, equipment, and criteria are discussed.

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EXECUTIVE SUMMARY

The flight test evaluation described in this report is part of a study on the use of Loran C for nonprecision approaches conducted by the Federal Aviation Administration (FAA). The objectives of the project were: (1) to develop Loran C flight inspection methods for commissioning and periodic inspections, (2) to determine flight inspection equipment requirements, (3) to examine techniques to perform the task most effectively, and (4) to determine signal-in-space criteria. Flight tests were conducted by the FAA Technical Center at nine airports across the continental United States. The airports were those selected for a limited implementation Instrument Flight Rules (IFR) Loran C nonprecision approach program. The program is a cooperative effort between the National Association of State Aviation Officials (NASAO) and the FAA.

Approach plates used for each airport were developed by the Aviation Standards National Field Office (AVN). Each approach procedure was designed to overlay an approach procedure for an existing landing aid. Approach procedures were developed for Burlington International, VT; Bedford/Lawrence G. Hanscom Field, MA; Mansfield/Lahm Municipal, OH; Columbus/Ohio State, OH; Portland International, OR; Salem/McNary Field, OR; New Orleans/Lakefront, LA; Orlando Executive, FL; and Beaumont-Port Arthur/Jefferson County, TX. AVN provided a flight check pilot authorized to approve each procedure.

An Advanced Navigation Inc. ANI-7000 Loran C receiver was used to measure Loran C signals-in-space and for navigation. A Global Positioning System (GPS) receiver (Magnavox Z-set) was used as the aircraft position reference system. Each approach procedure was flown three times; once using guidance from the underlying landing aid and twice using guidance from the Loran C receiver. A coverage box pattern was flown which started 10 nautical miles (nmi) before the first waypoint on the procedure and continued 10 nmi past the last waypoint on the procedure. Sides of the box pattern were 2 nmi and 10 nmi on both sides of the procedures.

Approach procedures were approved at all airports listed above except at Beaumont, TX, which was located near a baseline extension. Several of the airports required repeat check flights due to large positional errors caused by incorrect area calibration values.

Analysis of results has indicated deficiencies in the measurement of envelope-to-cycle difference (ECD) and signal-to-noise ratio (SNR) by the flight check receiver, incorrect area calibration values, and the need for calibration standards/procedures for the flight check receiver.

INTRODUCTION

OBJECTIVES.

The objectives of this project were: (1) to develop Loran C flight inspection methods to accomplish commissioning and periodic inspections, (2) to determine flight inspection equipment requirements, (3) to examine techniques to perform the task most effectively, and (4) to determine signal-in-space criteria.

BACKGROUND.

Loran C is a random area navigation system (RNAV) not restricted by line-of-sight between the receiver and transmitter. Loran C has the potential to provide nonprecision approach guidance at locations not serviced with conventional approach aids. The proliferation of commercially available low cost Loran C receivers has attracted the interest of various user groups. The National Association of State Aviation Officals (NASAO) is very enthusiastic about Loran C and the prospect of nonprecision instrument approaches to many airports. NASAO and the Federal Aviation Administration (FAA) have formed a cooperative effort to resolve outstanding issues and implement nonprecision approaches on a limited basis at designated sites in Vermont, Massachusetts, Ohio, Florida, Louisiana, and Oregon.

In order for an aircraft pilot to use an approach procedure under Instrument Flight Rules (IFR), the procedure must be approved and flight checked by the Aviation Standards National Field Office (AVN). The purpose of the flight check is to determine the quality of the signal-in-space and insure a safe, flyable procedure. At present, AVN does not have the necessary equipment, technical expertise, or methodology to flight inspect Loran C nonprecision approaches. To support the implementation effort, the FAA established this project which combined the necessary equipment and technical support of the FAA Technical Center with the certification authority of an AVN flight check pilot. The FAA Technical Center was responsible for providing technical guidance on Loran C, providing the necessary equipment including an aircraft, collecting flight check data, and developing guidelines for future flight checks. Ultimate certification of each approach procedure was the responsibility of the AVN flight check pilot with input from the Technical Center. AVN was also responsible for developing the approach procedure into each airport. The end goal of the project was to provide AVN with the technical information and support needed for them to become self-sufficient in flight checking Loran C nonprecision approaches.

AVN developed approach procedures to the nine airports included in the limited implementation nonprecision approach program. The ninth airport was located in Texas and proved not to be certifiable. Each Loran C nonprecision approach was designed to overlay an existing Instrument Landing System (ILS) approach.

RELATED DOCUMENTS.

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EQUIPMENT

AIRCRAFT.

An FAA Technical Center Convair CV-580 aircraft was used for all flight check work.

LORAN C RECEIVERS.

The aircraft was equipped with five airborne Loran C receivers: Teledyne TDL-711, Micrologic ML-4000, Texas Instruments TI-9100, and two Advanced Navigation ANI-7000 units. All units were production units available for commercial sale. The ANI-7000 receivers were used for primary data collection. Other receivers were used for additional information when needed during the flight check.

The ANI-7000 receiver was selected for use because it was an airborne receiver derived from the Austron 5000 Loran C receiver and was expected to adequately

measure signal-to-noise ratio (SNR's), envelope-to-cycle difference (ECD's) and time difference (TD's). The Austron 5000 is used by the United States Coast Guard (USCG) as a control monitor in the operation of the various Loran C chains. Software versions for the ANI-7000 Loran C receivers used during the tests were: Navigation-5.09, Receiver-4.14, and Output-1.07. Early tests used software versions 5.08, 4.14, and 1.07, respectively. These versions of software do not meet the current version of the Radio Technical Commission for Aeronautics (RTCA) Loran C Minimum Operational Performance Standards (MOPS) item 1, "Related Documents." The receiver did not identify the stations selected in accordance with standard USCG nomenclature (M, W, X, Y, Z) and did not accept area calibration values as a TD bias.

COCKPIT DISPLAY AND CONTROLS.

The Loran C receiver control heads were mounted in the rear cabin of the Technical Center CV-580 and were not accessable to the pilots. Crosstrack deviation and navigation valid flag were provided to the pilot on a course deviation indicator (CDI). Distance to waypoint was provided to the pilot on a separate distance measuring equipment (DME) indicator.

AIRBORNE DATA ACQUISITION SYSTEM.

A Norden militarized PDP 11/34M computer was used to collect the data. The data were recorded on a Miltope nine-track tape recorder. A Technical Center designed aircraft systems coupler (ASC) was used to interface the Loran C receiver and position reference system to the Norden computer. Data recorded on the nine-track tape are presented in table 1.

POSITION REFERENCE SYSTEM.

A Magnavox GPS Z-set receiver was used as the position reference. Flights were scheduled when four satellites were in view with good geometry. Expected accuracies are 40 meters, 2 sigma.

SPECTRUM ANALYZER.

A Tektronix 7L5 spectrum analyzer was used to monitor the Loran C spectrum. Signals were obtained from a Bayshore UPS-190 antenna.

DATA REDUCTION.

A Hewlett-Packard HP-1000 minicomputer was used to process all data. All data reduction programs were written in Fortran IV.

DISCUSSION

FACTORS AFFECTING ACCURACY AND INTEGRITY.

Performance of Loran C receivers are affected by geometric dilution of precision (GDOP), TD bias corrections, interference, SNR, and ECD. Accuracy of the Loran C receiver is affected by TD bias, interference, and GDOP. For the most part, SNR and ECD affect the integrity of the system.

TABLE 1. RECORDED DATA

Aircraft Sensors and Time

Time:	Hours, minutes, seconds
LTN-51 INS:	Present position, heading, track angle, ground speed
ADC-80:	True airspeed, altitude
VOR No. 1:	Bearing
VOR No. 2:	Bearing
CDI:	Analog CDI
GPS:	Present position, velocities, and time

Loran C Receivers Recorded

	TDL-711	ML-4000	ANI-7000	TI-9100
Present position lat/long	x	x	x	x
Station status	-	M+5	8	-
Station SNR's	M+3	M+5	8	-
TD's	2	2	8 TOA	-
ECD's	M+3	-	8	-
To waypoint lat/long	x	x	x	x
From waypoint lat/long	x	x	-	x
Crosstrack error	x	x	x	x
Ground speed	-	x	x	x
Distance to go	x	x	x	x
Front panel switch setting	-	x	x	-
En route/approach	-	-	x	-
Annunciator lamps	-	-	x	-
Receiver status	x	-	x	x
Grid reference	-	-	x	-
Bearing to waypoint	-	-	x	x
Desired track	-	-	x	x
Estimated time en route	-	-	x	-
Notch filter setting	-	-	x	-
Secondary phase delay	-	-	x	-
Triad in use	-	-	x	-
Station field strength	-	-	x	-

Note:

x = Data present in digital output
M = Master
TOA = Time of arrival
INS = Inertial Navigation System
GPS = Global Position System

GDOP is a function of the Loran C receiver location with respect to the Loran C transmitters. It can be calculated by knowing the position of the receiver and each of the stations in the required triad. GDOP remains constant for any given point and triad. GDOP must be considered when developing an approach procedure for an airport. It has been shown that GDOP determines the standard deviations of the position errors(item 2, Related Documents). The larger the GDOP the larger the standard deviations. GDOP is one parameter being used to decide if an airport can qualify for an approach procedure. Currently, GDOP is being calculated for a single point on the airfield such as the runway threshold, airport reference point, or local area Loran C monitor.

While this method addresses the area in general, it does not take into account areas where GDOP can change quickly such as when near a baseline extension. It also does not indicate when in close proximity to a transmitter. Each condition may be encountered when the aircraft is coming in for an approach. Methods can be developed to show procedures specialists were such problems may exist to help them develop a procedure. One such method would be to use a computer program, like the MITRE Airport Screening Model, and compute GDOP for several points around the airport. The computer program could be modifed to output distance from the point of interest to the Loran C transmitter. Flight into a baseline extension results in bad GDOP, increased position errors, and the possibility of a wrong position solution by the receiver. If the flight is very close to the transmitter (8 nautical miles (nmi)) the Loran C signal will be very strong and not formed correctly, which may cause a receiver to lose track and then stop reporting a position.

Loran C receivers measure TD's and convert present position in TD's to a geodetic position. The conversion of TD's to a geodetic position must assume some speed of propagation for the Loran C signals. Propagation of Loran C signals is very complex; therefore, models are only an approximation of the actual values. The difference between measured TD values at some geodetic position and model calculated TD values is known as a TD bias. If the TD bias is determined for a specific area it can be used to correct the Loran C position for variations in the propagation delay of the signals. The correction is much like the altimeter setting used to compensate for variations in local pressure. At present, a monitor will be placed at or near all airports approved for Loran C nonprecision approaches to determine the TD bias. Because TD bias is used in the conversion of TD's to geodetic position, it has a direct effect on positioning accuracy. Accuracy of the TD bias depends upon the correct measurement of TD's at a point, knowing the exact location of the point, and proper calculation of model TD's.

Interference may cause acquisition problems and shifts in position. Sources of interference are low frequency communications, power line carriers (PLC), and noise. Interference may be synchronous, near synchronous, and nonsynchronous.

Types of interference are important because of varying effects on the Loran C receiver. Synchronous and near synchronous sources of interference can cause shifts in position with small amplitude signals. Nonsynchronous interference must be large in amplitude for it to affect a receiver. In general, a large amplitude interfering signal tends to saturate the front end of the receiver causing ringing and deformation of the Loran C signals. The deformed signal causes acquisition problems, shifts in TD's, and, at times, loss of track. Large amplitude interfering signals can easily be seen on a spectrum analyzer. More

important, but harder to detect, are low amplitude signals that are near synchronous or synchronous. These signals cannot be easily detected with a spectrum analyzer.

The easiest way to detect the signals is to look at the effect. The effect should be a shift in position. Once the effect is seen and the affected area defined, a much closer look at the spectrum is required to define the signal. Low frequency communication stations are generally known and removed with notch filters in the Loran C receivers. The USCG has published several lists of known interfering frequencies. Another possible source of interference is the power lines. Power line companies are currently superimposing signals on the power line to control selected equipment as well as for communications. The signals are placed on the power lines and are not intended to radiate; however, they do in fact radiate. Some systems are on continuously while others are turned on only when needed.

SNR is the signal-to-noise ratio of the Loran C signal. SNR is defined by the USCG as the ratio of the Loran C signal to the noise. The Loran C signal strength is measured at the 25 microsecond point of the pulse. Signal strength is defined as the root-mean-square (rms) level of a sine wave equal in amplitude to the Loran C pulse at the measurement point. Noise is defined as the true rms level of the noise through a 30 Kilohertz (kHz) bandpass filter centered at 100 kHz. The MOPS does not include cross-rate interference or continuous wave interference in the definition of noise. SNR affects the acquisition time, time to detect station outage, time to detect blink, and the ability to detect the proper tracking point of the pulse. Once a Loran C receiver has acquired a Loran C signal it will generally track the signal with a much lower SNR. Generally, SNR will remain constant within a geographic area. Field strength is dependent on the propagation path. Noise is generally from atmospheric sources such as lightning. Noise, however, can be local, e.g., such as a charge build-up on an aircraft due to precipitation static. The amount of charge build-up on an aircraft is a function of the aircraft and the static discharge system.

ECD is the envelope-to-cycle difference. It describes the relationship of the pulse shape to the carrier. Maintaining a signal's ECD within limits is necessary to assure proper acquisition and track of the Loran C signal. The envelope (slope) of the pulse is used in defining the proper tracking point of the pulse. ECD is defined by the USCG in terms of the current entering the transmitter antenna. ECD is shifted 2.5 microseconds from the input of the antenna to the far field signal in space. Therefore, a nominal ECD of 0 antenna current will produce a signal with a +2.5 microsecond ECD. ECD varies as a function of distance from the transmitter. Mountainous terrian is also known to affect the ECD.

Two issues must be considered when evaluating accuracy during a flight check, TD bias and waypoint resolution. The best results would be obtained if current TD bias corrections and high resolution (0.01 minutes) waypoints are used in the flight check receiver. Results should be better than obtained from a MOPS receiver using published TD bias corrections and waypoint resoutions of 0.1 minutes.

The effect of waypoint resolution is a function of the actual waypoint value. Waypoint resolution of 0.1 minutes is equivalent to a step size of better than 600 feet. Step size is reduced to better than 60 feet with a resolution of 0.01 minutes. If the actual runway waypoint was halfway between the resolution of the waypoints, errors of 300 and 30 feet would result for waypoint resolution of 0.1

and 0.01 minutes, respectively. TD bias corrections may introduce errors because the published correction is a predicted value and may not be equal to the current correction. The difference between the values will be seen as a position error.

DESCRIPTION OF TESTS.

Based on previous Loran C nonprecision approach experience, a method was established to flight check the airports in the limited implementation program. From the additional experience gained while flight checking the airports in the limited implementation program, guidelines for future flight checks of Loran C nonprecision approach procedures were developed.

It was decided the flight check should include at least two types of tests. The first test would determine the signal-in-space characteristics, flyability of the procedure, interference, and system accuracy for each segment of the Loran C approach. The second test, called the box pattern, would determine the signal-in-space characteristics in an area around the approach procedure. Requirements for the second test were based on a desire to insure adequate signals in the vicinity of the airport for reliable navigation. Accuracy in the box pattern was not considered critical.

The approach phase of the tests consisted of three approaches. The first approach (run) was flown using guidance from the underlying localizer. This approach provided a means to compare the Loran C approach with the underlying localizer approach. Runs two and three used navigation guidance from the Loran C receiver. These runs provided information on the flyability of the approach. At least one run of the three approaches went from the first waypoint on the approach to the last waypoint on the approach. Along-track error (ATE) and crosstrack error (CTE) for Loran C were computed on all runs and segments. Computation of ATE and CTE were derived from GPS (aircraft reference) and Loran C present positions. ATE and CTE were then compared to FAA Advisory Circular (AC) 90-45A item 3 Related Documents for compliance. In addition, flight technical error (FTE) and total system crosstrack (TSCT) error were computed for runs where Loran C guidance was flown. FTE and TSCT were compared with AC 90-45A limits for use as an indicator of problems with an approach procedure. Means and standard deviations were calculated for each parameter, segment, and run. A mean and standard deviation for each parameter was also calculated by combining data from each segment and run with valid data.

Valid data were defined as the Loran C receiver properly tracking the required chain/triad, the correct area calibration values entered into the Loran C receiver, and the GPS receiver using four satellites in its position solution with expected accuracies of 120 feet. The parameters included: field strength, ECD, SNR, TD bias, ATE, CTE, FTE, and TSCT. Localizer crosstrack deviation scaled in microamps and in feet were plotted with respect to distance from localizer. Distance to the localizer was determined from GPS data. GPS crosstrack deviation was also plotted on the same scale. These plots were used to verify that the GPS position was reasonable. Figure 1 shows a plot of the aircraft track for a typical Loran C nonprecision flight check. This particular aircraft track is for the Orlando Executive Airport. Approach plates for each of the airports appear in appendix A.

The box pattern was designed to measure signal-in-space characteristics, 10 nmi before the first waypoint on the approach, to 10 nmi past the last waypoint on the approach. If the first or last waypoints included a holding pattern, it also was included. Flights were conducted 2 nmi and 10 nmi either side of the approach procedure at minimum vectoring altitudes. Loran C parameters were plotted versus

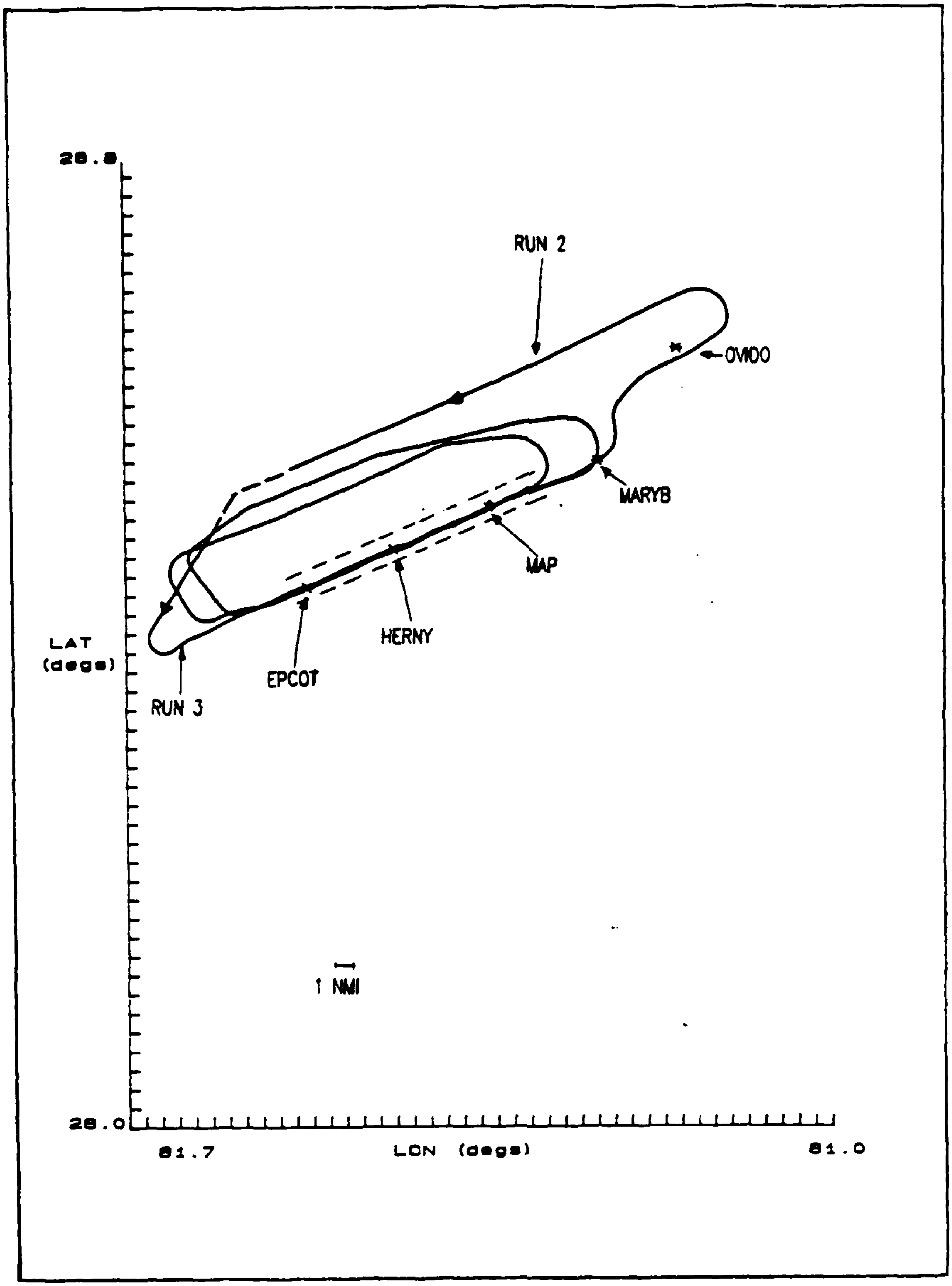


FIGURE 1. AIRCRAFT TRACK FOR LORAN C NONPRECISION APPROACH FLIGHT CHECK, ORLANDO EXECUTIVE AIRPORT

time for the box pattern (figure 2). Waypoints are denoted on the plot to correlate data with aircraft location in the box pattern. The parameters included present position of the aircraft (latitude and longitude), field strength, ECD, SNR, TD bias, and atmospheric noise for each station required on the approach plate. The upper section of the plot shows the latitude of the aircraft in degrees. The second section from the top shows the longitude of the aircraft in degrees. SNR derived from phase information (SNR(PH)) is shown in the third section from the top, while SNR derived from field strength and atmospheric noise (SNR(FS)) is shown in section four. Both sections are expressed in decibel (dB) and have a dashed line drawn at the 0 dB limit. Data above the line meets the criteria. Section five of the plot shows the field strength of the standard sampling point of the Loran C pulse (FS) expressed in dB above 1 microvolt per meter. Atmospheric noise is expressed in dB above 1 microvolt per meter and is shown in section 6 of the plot. ECD values expressed in microseconds are shown in section 7 of the plot. Dashed lines are drawn at plus and minus 2.4 microseconds, the established limits. Data inside the dashed lines meet the criteria. The bottom section of the plot shows the TD bias expressed in microseconds. TD bias is the difference between a calculated TD based on a Defense Mapping Agency (DMA) seawater value and the measured TD value. Waypoints are shown at the bottom of the plot as a line with a number. The number is the waypoint and corresponds to the number appearing on figure 3 of the box pattern. Figure 3 is a plot showing the aircraft track with respect to the waypoints used to flight check the box pattern.

Table 2 lists the airports that were flown for the limited implementation program. Listed in the table is the name of the airport, the airport ID, the runway with the approach procedure, the required chain and triad, the GDOP in feet/microsecond at the airport per the MITRE Airport Screening Model, and the status of the approach procedure. Table 3 lists the dates when flight checks were performed at each of the airports.

RESULTS

In this section, results of the flight check work conducted at nine airports in the limited implementation program are presented in summary form. More information may be obtained from items 4 to 19, Related Documents which are reports on specific flight checks. These reports were furnished to AVN and APM after the flight check. During the flight check of Beaumont-Port Arthur Airport, the ANI Loran C receivers used for the flight check acquired the proper chain/triad while on the ground, but reported poor geometry. Several of the other Loran C receivers on-board the aircraft would not acquire the required chain/triad or report a position. Once airborne, the ANI receivers annunciated a warning several times. Review of Beaumont's location with respect to the Loran C transmitters showed it to be close to the baseline extension. GDOP for the airport was 8999 feet/microsecond, well in excess of the 3000 feet/microsecond limit established for the limited implementation program. Based on flight observations and Loran C geometry, Beaumont-Port Arthur was determined to be unacceptable for nonprecision approaches and testing was stopped. No post-flight data processing was done for Beaumont, therefore, it does not appear in the data tables.

Table 4 shows a summary of the various Loran C parameters for each airport that was flight checked. All data in the table was measured by the ANI-7000 Loran C receiver. Column one lists the various parameters, they are:

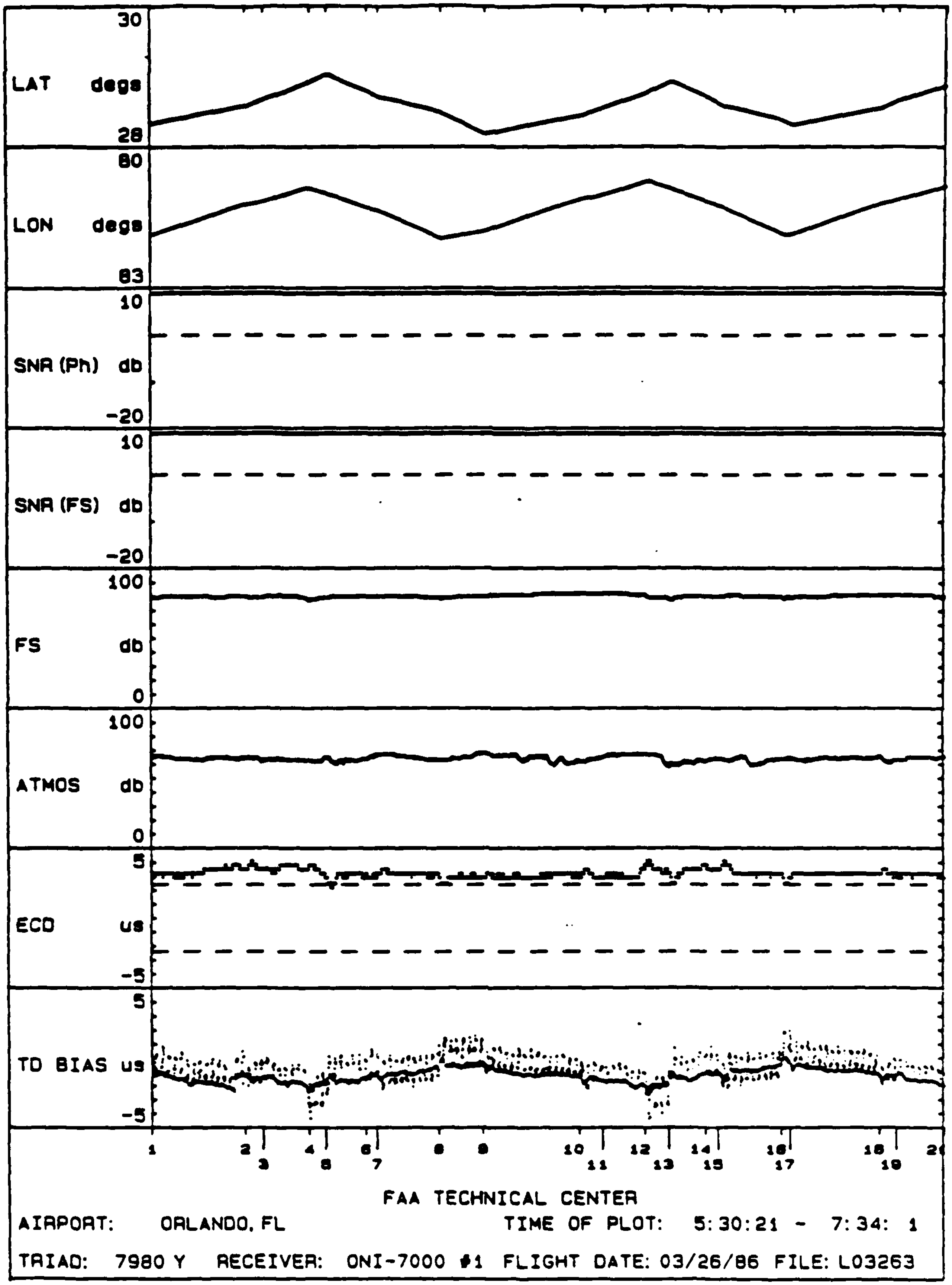


FIGURE 2. LORAN C PARAMETERS FOR BOX PATTERN, ORLANDO EXECUTIVE AIRPORT

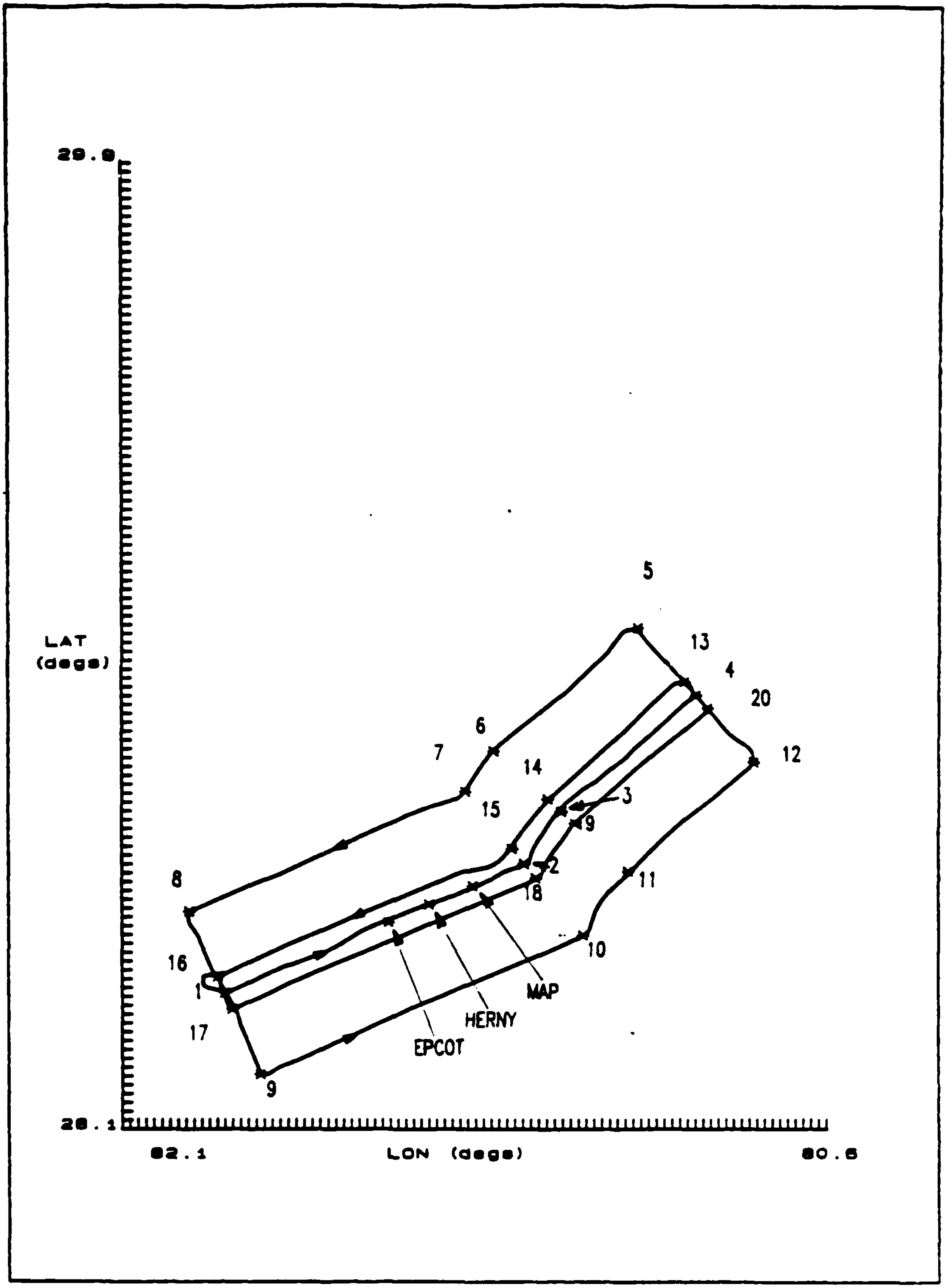


FIGURE 3. AIRCRAFT TRACK FOR BOX PATTERN, ORLANDO EXECUTIVE AIRPORT

TABLE 2. AIRPORTS FLIGHT CHECKED

Airport	ID	Runway	Chain	Triad	GDOP	Status
Burlington International, Burlington, VT	BTV	15	9960	MWX	1254	Approved
Bedford/Laurence G. Hanscom Field, Bedford, MA	BED	11	9960	MWX	956	Approved
Mansfield Lahm Municipal, Mansfield, OH	MFD	32	9960	MYZ	1087	Approved
Columbus/Ohio State University, Columbus, OH	OSU	9R	9960	MYZ	1006	Approved
Portland International, Portland, OR	PDX	10R	9940	MWX	2603	Approved
Salem/McNary Field, Salem, OR	SLE	31	9940	MWX	2359	Approved
New Orleans/Lakefront, New Orleans, LA	NEW	18R	7980	MWX	1309	Approved
Orlando Executive, Orlando, FL	ORL	7	7980	MYZ	1071	Approved
Beaumont-Port Arthur/Jefferson County, Beaumont-Port Arthur, TX	BPT	12	7980	MWX	8999	No

TABLE 3. FLIGHT CHECK DATES

Airport	Flight Check Dates
BTV	9/25/85
BED	6/18/85, 9/25/85
MFD	11/1-2/85, 1/28-29/86, 3/27/86
OSU	11/1-2/85, 1/28-29/86, 3/27/86
PDX	9/15/85, 12/17-18/85
SLE	9/15/85, 12/17-18/85
NEW	3/26-27/86
ORL	3/25-26/86
BPT	9/30/85

TABLE 4. SUMMARY OF LORAN C APPROACH PARAMETERS

Parameter		Airports							
		BTV	BED	OSU	MFD	PDX	SLE	ORL	NEW
SNR(PH) (dB)									
M	mean	9.00	9.00	9.00	9.00	8.51	8.87	9.00	9.00
	std. dev.	0	0	0	0	1.11	0.69	0	0
Sec 1	mean	9.00	9.00	8.99	8.58	9.00	9.00	9.00	9.00
	std. dev.	0	0	0.15	1.15	0	0	0 0	0
Sec 2	mean	9.00	9.00	9.00	9.00	8.08	8.70	9.00	9.00
	std. dev.	0	0	0	0	1.65	0.97	0	0
SNR(FS) (dB)									
M	mean	13.83	4.69	11.63	11.00	-14.13	-8.44	12.10	12.22
	std. dev.	0.83	1.41	1.17	0.76	0.67	0.67	1.57	1.41
Sec 1	mean	8.22	-5.32	1.51	-1.84	10.99	10.81	16.99	30.75
	std. dev.	1.34	0.88	1.37	0.95	0.73	0.58	1.35	2.94
Sec 2	mean	5.07	16.56	15.67	10.30	-14.12	-11.14	3.31	1.08
	std. dev.	1.05	0.91	1.37	0.82	0.74	0.55	1.42	1.62
ECD (microseconds)									
M	mean	1.33	1.67	2.96	3.25	0.13	1.69	3.07	3.29
	std. dev.	0.29	0.19	0.28	0.15	0.26	0.19	0.37	0.30
Sec 1	mean	2.06	1.34	1.49	1.57	1.56	1.89	3.09	3.77
	std. dev.	0.31	0.33	0.23	0.27	0.22	0.13	0.34	0.25
Sec 2	mean	0.36	1.79	1.32	0.91	0.72	0.91	1.74	2.81
	std. dev.	0.23	0.28	0.23	0.25	0.37	0.25	0.33	0.32
TD Bias (microseconds)									
TD 1	mean	0.44	0.01	1.03	1.33	-1.61	-1.34	-0.98	-2.01
	std. dev.	0.64	0.53	0.44	0.32	0.42	0.45	0.51	0.67
TD 2	mean	0.10	-1.53	-1.48	-0.61	0.40	0.33	-1.66	-1.89
	std. dev.	0.60	0.59	0.67	0.46	0.45	0.22	0.62	0.65
Position Error (feet)									
ATE	mean	-159	-152	145	-502	-126	-295	-214	108
	std. dev.	160	170	142	159	184	216	106	380
CTE	mean	212	184	-226	-162	220	-148	-182	-138
	std. dev.	135	163	192	128	169	197	83	330

1. SNR(PH) is the SNR as measured from phase information.

2. SNR(FS) is the SNR as measured from the field strength and atmospheric noise.

3. ECD is the envelope-to-cycle-difference.

4. TD bias is the difference between the measured TD and a computed TD based on the DMA seawater propagation model, in effect, the area calibration value.

5. Position error is the ATE and CTE for each airport.

6. "M" is used to indicate a master.

7. "Sec 1" is used to indicate the first secondary of a triad.

8. "Sec 2" is used to indicate the second. (Refer to table 2 for the required chain and triad at each airport.)

9. "TD1" is used to indicate the first time difference formed by the master and the first secondary of the required triad.

10. "TD2" is used to indicate the second time difference formed by the master and the second secondary of the required triad.

The mean and standard deviation for each of the parameters are included in the table. Data appearing in the table are the statistical combination of valid data from all segments and runs at an airport. Valid data are all data collected when the Loran C receiver was correctly tracking the required stations, the radiated Loran C signals were within USCG specification, the correct area calibration values were inserted in the receiver, and the GPS was operating correctly. Columns two through nine contain the data for Burlington, VT (BTV); Bedford, MA (BED); Ohio State University, OH (OSU); Mansfield, OH (MFD); Portland, OR (PDX); Salem, OR (SLE); Orlando, FL (ORL); and New Orleans, LA (NEW), respectively. Information about the airport runway, required chain/triad, and correct title of the airport may be found in table 2.

Summary of flight data for the box pattern appears in table 5. Flight data for the box pattern were plotted. The results appearing in table 5 indicate if the various Loran C parameters meet the required limits. Two entries appear in the table for each airport and parameter. The first entry indicates if the parameter meets the original requirements for the implementation program; the second entry in the table indicates its status with respect to new modified requirements. At the beginning of the flight testing, the requirements for the Loran C parameters were 0 dB SNR and an ECD of ± 2.4 microseconds (first entry).

As time progressed, work on the RTCA Loran C MOPS also progressed. In an effort to expand the Loran C user area for nonprecision approaches, new limits for testing and compliance of Loran C receivers were under investigation. At present, the values of -6 dB SNR using atmospheric noise and an ECD limit of +3.0 microseconds for SNR values greater than 0 dB and -2.4 microseconds for SNR values greater than -6 dB is proposed. The second entry in the table is compared to this proposed limit.

Table 5 contains three items which must be explained: the failure of SNR(PH), SNR(FS), and ECD to meet the newly established criteria (second entry) at several airports. SNR(PH) for Sec 2 at Salem failed to meet the criteria because of a short duration dip in the SNR. The dip in SNR was also seen on the Master but did not cause it to go below the criteria. No effect was seen on Sec 1 due to the extremely high SNR for this station. SNR for other areas of the box pattern and a repeat flight through the affected area did not show any other dips. Due to the short duration of the dip in SNR, it was decided it would not affect the receiver operation and the airport should be approved.

Failure of SNR (FS) to meet the new criteria at Bedford (BED), Salem (SLE), and Portland (PDX) was due to a deficiency in the measurement of the parameter by the Loran C receiver. The deficiency was in the measurement of noise due to the proximity to a Loran C transmitter. This deficiency will be discussed later.

TABLE 5. SUMMARY OF FLIGHT DATA FOR THE BOX PATTERN

	Airports							
Parameter	BTV	BED	OSU	MFD	PDX	SLE	ORL	NEW
SNR(PH)								
M	P P	P P	P P	P P	P P	F P	P P	P P
Sec 1	P P	F P	P P	P P	P P	P P	P P	P P
Sec 2	P P	P P	P P	P P	F P	F F	P P	P P
SNR(FS)								
M	P P	F P	P P	P P	F F	F F	P P	P P
Sec 1	F P	F F	F P	F P	P P	P P	P P	P P
Sec 2	P P	P P	P P	P P	F F	F F	F P	F P
ECD								
M	P P	P P	F F	F F	P P	P P	F F	F F
Sec 1	P P	F P	P P	P P	F P	P P	F F	F F
Sec 2	P P	F P	F P	F P	P P	P P	F F	F F

Note: First entry based on limits of 0 dB SNR and +-2.4 us ECD.
Second entry based on limits of -6 dB SNR and +3 us to -2.4 us ECD
P = Meets requirements.
F = Does not meet requirements.
Failure of SLE to pass SNR(PH) limit for Sec 1 was due to a momentary dip in SNR of short duration.
Airports not passing the ECD criteria exceeded the positive limit due to expected measurements problems.

ECD for several of the airports failed to meet the criteria because the positive limit of the criteria was exceeded. According to theory, ECD near a transmitter should be equivalent to the value input to the transmitter antenna shifted by +2.5 microseconds. ECD should decrease with distance from the transmitter. Because actual measurement of ECD did not agree with theory, the Loran C flight check receiver was tested on a simulator. Limited testing indicated a deficiency in the measurement of ECD by the receiver. ECD measurements were found to be incorrect by up to 0.5 microseconds. Based on these results, it was decided the airports which did not meet the ECD criteria should be approved.

Many of the problems which influenced the quality of results or caused flight checks to be redone do not appear in tables 4 and 5. These problems involved incorrect area calibration values, mixed geodetic datums, measurement inaccuracies, Loran C geometry, interference, incorrect information on the approach plates, and variation of the Loran C signals-in-space. Due to the nature of these problems, data to support each problem will appear with the analysis in the next section, "Analysis of Results."

ANALYSIS OF RESULTS

In this section the results of the flight check work conducted at the nine airports in the limited implementation program are analyzed. The objectives of the project were to develop guidelines for certifying future Loran C IFR nonprecision approaches. Areas which will affect flight check procedures that are addressed in this section are:

1. Incorrect area calibration values
2. Mixed geodetic systems
3. Measurement inaccuracies
4. Baseline extensions
5. Interference
6. Shifts in TD's
7. Approach plate information
8. Variation of signal parameters for an approach
9. Variation of signal parameters for the box pattern

INCORRECT AREA CALIBRATION VALUES.

To achieve the required accuracy, Loran C receivers must use an area calibration value. The calibration value compensates for the difference between a propagation model and the actual propagation of the Loran C signal. The propagation model is used by the Loran C receiver to compute geodetic position.

Area calibration functions much the same way as an altimeter setting compensates a barometric altimeter for changes in the barometric pressure. To insure consistency between Loran C receivers, a common propagation model must be used. The computation of area calibration values must also use this common propagation model. The propagation model must specify the resolution of the geodetic positions, the geodetic datum, the distance computation equations, and the speed at which the Loran C signals propagate. At present a DMA propagation model has been adopted by the RTCA as the nonprecision approach model.

Loran C area calibration values are determined from a local area monitor. The purpose of the monitor is twofold: (1) to record variations in the TD's so future calibration values can be determined, and (2) to alert air traffic/pilots to conditions that would cause a Loran C equipped aircraft using the published area calibration values to exceed safe airspace. Accuracy of the area calibration value is, therefore, a very important part of the airborne Loran C receiver position accuracy.

Three of the nine airports flight checked had incorrect published area calibration values. The three incorrect area calibration values were caused by

errors in the geodetic positions determined for the local area Loran C monitor. In two of the cases the error was easily noticed in flight as a large crosstrack position offset from runway centerline. In the third case the aircraft was positioned close to the runway centerline with no problem detected during the flight check. Detection of the problem was found in post-flight data processing. The only clue was a large difference between the TD bias recorded at the monitor and that used for area calibration of the airborne Loran C receiver. The problem was found to be incorrect geodetic position and time differences for the local area monitor. Very small ATE and CTE values were measured because of the nature of the errors. Area calibration is the process of making predicted TD's for a geodetic point equal to the actual TD's at the same point. The actual point used for the measurement is not critical as long as it represents the area of interest. It this case, the incorrect TD's were shifted in position by the same amount as the incorrect geodetic position. The net result was a cancellation of errors. A detailed analysis can be found in appendix B.

During a follow-on project to conduct seasonal Loran C flight checks, new software was obtained for the ANI-7000 Loran C receiver. The new software added the ability to enter area calibration values as a TD bias required by the RTCA MOPS. Two new problems were uncovered: inaccuracies in the TD model and a large position error at one airport. In preparing for the seasonal flight checks, it was necessary to compute the model TD's for the runway threshold. For convenience, an in-house software program was used instead of the MITRE Airport Screening Model (item 20 Related Documents), which was used in the calculation of the published area calibration values. The in-house software implemented the DMA seawater propagation model as required by the RTCA MOPS and assumed to be implemented in the MITRE Airport Screening Model.

To insure consistency between software, TD's were calculated for the airport monitor and compared to the published values. Small differences were found to exist between the two sources. Review of the software implementations determined that the MITRE Airport Screening Model did not use the same values as the DMA Seawater Model. These differences did not affect the computed TD's significantly. A more subtle difference between the two software programs was the resolution of the Loran C transmitter geodetic positions. Resolution of geodetic positions for the propagation model are not specified in the RTCA MOPS. Software implementations by the DMA and the Technical Center resolve geodetic positions to better than 1 foot, while those in the MITRE Model resolve geodetic position to 365 feet or less. Insufficient resolution for the Loran C transmitter geodetic positions in the MITRE software caused the largest difference between the in-house software and the MITRE software. A more detailed description of the problem can be found in an ACT-100 Engineering Report titled "TSC Saltwater Model Time Differences" (item 19 Related Documentation). The second problem had to do with the Loran C receiver implementation of the area calibration value.

Prior to flight, the Loran C receiver was checked on a Loran C simulator to verify it had correctly implemented the area calibration entry change. Checks were limited to only one or two points. The receiver worked as expected. When flights were conducted at New Orleans/Lakefront Airport using TD bias corrections large position errors were encountered. Use of the area calibration values, which included the geodetic position of the monitor and measured TD's, produced small position errors. Post-flight analysis showed the published TD bias values were correct but that the Loran C receiver did not correctly use the information. New Orleans is only 59 nmi from the Grangeville transmitter and is

the only airport in the limited implementation program located closer than 86 nmi to the transmitter. At 86 nmi the DMA seawater propagation model changes constants. It is expected that the problem is due to this shift in constants at distances less than 86 nmi from the Loran C transmitter. The problem is being investigated by the manufacturer.

MIXED GEODETIC DATUMS.

Currently two geodetic datums are being mixed in the limited implementation Loran C program: the North American Datum of 1927 (NAD-27) and the World Geodetic System of 1972 (WGS-72). Mixing of different geodetic datums introduces position errors into Loran C nonprecision approaches. At present, all waypoints appearing on the approach plates and in the National Airspace System (NAS) are in the NAD-27 datum.

The Loran C community and Transportation Systems Center (TSC), who publishes the TD bias corrections, are currently using the WGS-72 datum. A geodetic datum describes the shape of the earth; any point can be related to that datum. Given a point, its geodetic position can be determined. Each geodetic datum will describe a specific point with a different set of latitude and longitude values. Because latitude and longitude are one universally accepted method to describe a position, they are used in the computation of distance and bearing information. Given two points, both in the same geodetic datum, the distance and bearing between them will be almost identical whether they are both in WGS-72 or NAD-27 datums. The distances calculated would also agree very closely with the actual physically measured distance between the points. If, however, the latitude and longitude for one point is in the WGS-72 datum and the other in the NAD-27 datum, the distance and bearing would not agree with the physically measured values. Table 6 shows the difference that exists between the latitudes and longitudes of a physical point if measured in the WGS-72 and NAD-27 datums. Data are included for each airport in the limited implementation program. The Abridged Moldensky equations (item 21 Related Documents) were used to determine the values in the table.

Portland, OR, is a good airport to demonstrate the difference between WGS-72 and NAD-27 datums because of the large shift, 95 feet northing and 338 feet easting. To show the effect on receiver position accuracies, two areas will be addressed:

1. Verification that the position reference system (GPS) correctly measures the aircraft position with respect to the actual position of the runway on the earth.

2. Comparison of Loran C position accuracies.

Regardless of what method is used to determine the location of a runway, it must be able to guide an aircraft to the actual runway on the earth. Localizers provide guidance information referenced with respect to the runway centerline. Absolute position of the localizer is not important as long as it is located correctly with respect to the runway. Earth referenced systems, such as Loran C, Omega, GPS, and INS, report position with respect to a geodetic datum. Before looking at the effect of mixed geodetic datums on Loran C accuracy, it is necessary to verify that the aircraft reference system (GPS) is referenced to the runway on the earth. It was also important to verify that GPS was operating properly.

TABLE 6. POSITION DIFFERENCES BETWEEN NAD-27 AND WGS-72 DATUMS

Airport	Northing (ft)	Easting (ft)
Portland, OR	95	338
Salem, OR	95	340
Beaumont, TX	-78	107
Orlando, FL	-100	-6
New Orleans, LA	-81	72
Burlington, VT	-9	-80
Bedford, MA	-7	-97
Ohio State Univ., OH	-7	9
Mansfield, OH	-4	5

Note: NAD-27 minus WGS-72

Verification of the aircraft reference system (GPS) was accomplished by comparison with localizer data because it is physically located at the runway. Information from the localizer is, therefore, referenced to the runway centerline. Standard flight check reports (Form 8240-7) were used to verify the localizer alignment and course width. Run 1 of the tests were flown using the localizer for course guidance and to visually verify the localizer performance. Localizer deflections in microamps were converted to a crosstrack displacement from the runway centerline extension in feet. Distance to the localizer was needed to perform the conversion and was calculated using the GPS position and localizer position. Localizer geodetic position and runway bearing were defined in the NAD-27 datum to agree with the geodetic datum used on the approach plates. Errors in the GPS distance to localizer would cause only small errors in the conversion of the localizer information to crosstrack displacement in feet. Sensitivity of crosstrack displacement to errors in the distance to localizer is a function of the angle formed by the aircraft position, localizer, and the runway centerline extension. As the angle becomes larger, the sensitivity also gets larger. If the aircraft were 1000 feet off centerline at the threshold and a distance to localizer error of 100 feet were present, it would affect the crosstrack displacement by 8 feet.

Because localizer data describes the aircraft position with respect to the runway centerline, it is a measure of TSCT which can also be calculated from GPS data. If GPS data are correct, TSCT calculated from localizer data and from GPS data should be the same. Figure 4 shows TSCT plotted as a function of distance from the localizer. The plot shows TSCT data calculated from localizer information, GPS data using the NAD-27 datum, and GPS data using the WGS-72 datum

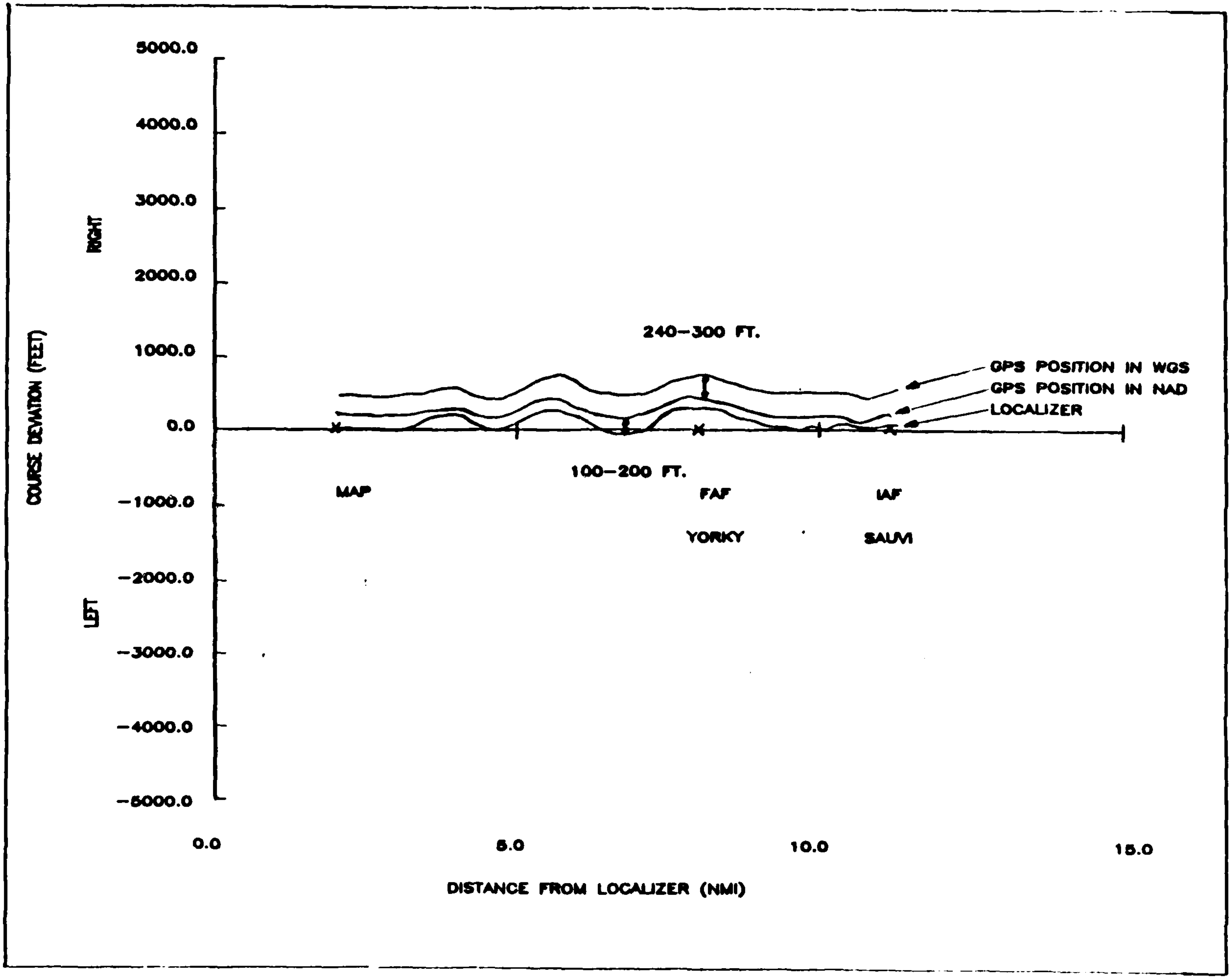


FIGURE 4. TSCT VERSUS DISTANCE FROM LOCALIZER FOR PORTLAND (RUN 1)

for run 1. From the figure it can be shown that the localizer data and GPS data using the NAD-27 datum agreed to within 150 feet. GPS data using the WGS-72 datum is shifted 240 - 300 feet further to the right than the GPS data using the NAD-27 datum. Figure 5 is laid out similar to figure 4 but shows data from run 3.

In figure 5 the localizer data and GPS data using the NAD-27 datum have good agreement from the FAF to MAP. GPS data using the WGS-72 datum shows a shift of approximately 300 feet to the right of the localizer data. The results of run 1 and run 3 show that TSCT from localizer data and GPS data agree as long as all information is in the NAD-27 datum. This also implies GPS data are correct with respect to the actual runway location on the ground. TSCT from localizer and GPS data in the WGS-72 datum differ by approximately 300 feet. If the difference between datums were rotated with respect to the runway, a difference in the direction to the runway of 284 feet and 281 feet perpendicular to the runway would be expected. The perpendicular distance would show up in the TSCT measurement. Therefore, measured and theoretical results are in close agreement. It is very important to note that a similar argument could be made for using GPS data in the WGS-72 datum if the waypoints and locations of the localizer were in the WGS-72 datum and not in NAD-27 coordinates as currently published. Since all waypoints are in the NAD-27 datum, GPS data using the NAD-27 datum should be used to evaluate Loran C accuracy because it relates everything to the actual placement of the runway on the earth.

Thus far we have shown that GPS data in the NAD-27 datum should be used to evaluate Loran C accuracy because the approach plate waypoints and runway ends are in the NAD-27 datum. TSCT cannot be used to evaluate the effect of area calibration because it includes FTE. ATE and CTE must be used in the comparison because it only includes navigation equipment error.

During the flight tests at Portland, two identical ANI-7000 Loran C receivers were flown. System number 1 used an area calibration value based on a local area monitor position in NAD-27 coordinates, and system number 2 in WGS-72 coordinates. Area calibration values based on local area monitor positions in WGS-72 coordinates is the currently used method. When all data were combined from runs 1 and 3 by receiver, the mean ATE and CTE for receiver number 1 were -126 feet and 220 feet, respectively. For receiver number 2, ATE was -366 feet and CTE was -67 feet. The values for receiver number 2, using area calibration based on a local area monitor position in WGS-72 coordinates were larger than for receiver number 1. The difference between system number 1 and system number 2 for ATE was 287 feet and 240 feet for CTE. As stated earlier, the expected shift between the two systems would be 284 feet for ATE and 281 feet for CTE. The reason ATE and CTE is not zero when using GPS data in the NAD-27 datum is due to errors in GPS position. Review of figures 4 and 5 show GPS data in the NAD-27 datum close to the localizer data, but still in error by 100 to 200 feet. The measured results are very close to the theoretical.

In summary, it was shown that errors are, in fact, introduced into the Loran C receiver accuracy because of mixed geodetic datums. The errors can be reduced by using area calibration values based on local area monitor position in NAD-27 coordinates. A better method would be to require everyone to use the same geodetic datum. This currently presents operational problems because the Loran C community uses the WGS-72 datum and the FAA uses the NAD-27 datum. Present plans by the FAA are to change to a new geodetic datum in the near future.

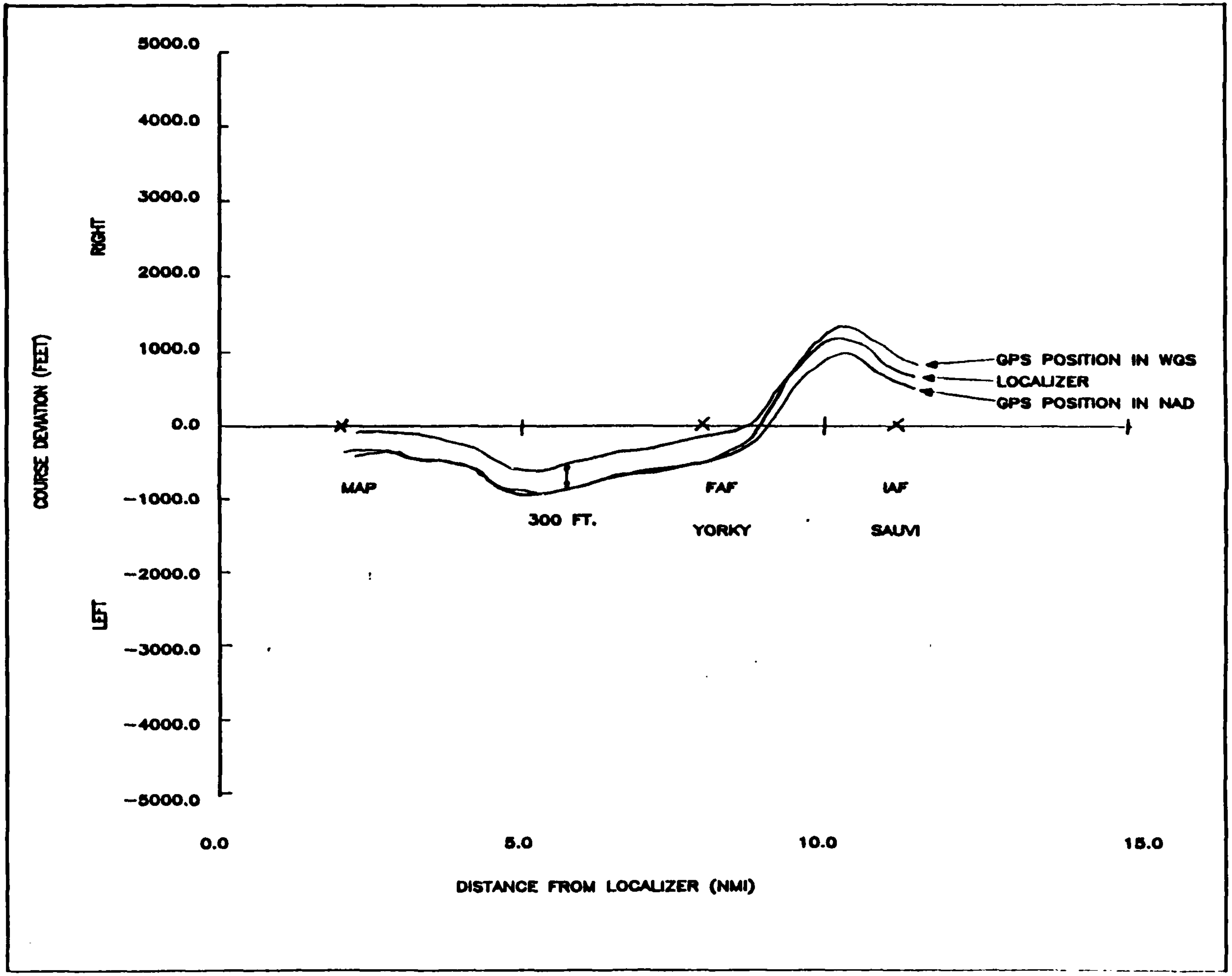


FIGURE 5. TSCT VERSUS DISTANCE FROM LOCALIZER FOR PORTLAND (RUN 3)

MEASUREMENT INACCURACIES.

At several of the airports the measurements of SNR and ECD were not consistent with expected results. Review of table 4, which lists the results of the approach flights at each airport, shows a large difference between SNR(PH) and SNR(FS). ECD values in excess of +3.0 microseconds were also observed. These results point not only to possible deficiencies in the flight check receiver, but also to possible deficiencies in defining the measurements.

To understand the significance of the results, a brief description of basic Loran C receiver processing is necessary. A Loran C receiver is affected differently by Loran C transmitters, continuous wave interference (CWI) and atmospheric noise. Loran C transmitters operating on the same chain do not interfere with each other or with a Loran C receiver's ability to track individual stations on that chain. The reason is that only one station in a chain transmits at any one time. When more than one chain is operating in an area, crossrate interference is produced. Interference from crossrate only affects a Loran C receiver's acquisition and tracking ability if a pulse from the other chain is received during the reception of the desired pulse. The amount of interference is, therefore, a function of the number of pulses interfering with the desired pulses and not a function of the average rms level for all pulses of the interfering chain. Group repetition interval (GRI) rates are selected to minimize the effect of crossrate interference.

CWI may affect a receiver's ability to acquire and track Loran C signals. Notch filters are generally used to eliminate or attenuate the interfering signals. Filters may be fixed tuned or automatically tuned.

Atmospheric noise is generally broadband impulsive noise. The major source is lightning around the world, however, noise can also be generated by precipitation static or high power switching devices. Noise varies with the time of day and season. Noise, while random, is added to all Loran C pulses causing random distortion in both the envelope and carrier. The distortion requires the Loran C receiver to perform some kind of signal processing to estimate the actual Loran C signal to perform acquisition and track functions. The amount of noise allowed through the receiver is a function of receiver bandwidth and the number and depth of the notch filters. Loran C receivers generally implement some form of clipping or limiting which tends to eliminate or reduce the energy of large amplitude impulses.

A major difference exists between measurements of SNR and ECD in a simulator and from the real world. During simulation it is possible to measure well defined signals free from any other contamination. A flight check receiver must make measurements from a composite Loran C signal which includes noise, interference, and notch filters. Separating signals into individual parameters is, thus, a difficult task.

The flight check receiver used for this project was able to estimate SNR from phase information and by comparing field strength to atmospheric noise. The receiver implemented the atmospheric noise measurement by randomly sampling the energy received through the front end of the receivers. The measurement included energy from Loran C transmitters. Measurement of noise will, therefore, be higher than perceived by the acquisition and tracking loops of a Loran C

receiver. The amount the measurement will overestimate the actual noise will be a function of the sampling rate, the number of pulses, and the field strength. Noise measurements will be especially high when in close proximity to a Loran C transmitter. This effect was noticeable during signal coverage flights of the United States. As the aircraft would fly near a Loran C transmitter, the measured field strength of the transmitter and atmospheric noise became highly correlated. Refer to "Loran C Spring Stability Data Report" (item 22 Related Documents) for plots of this data. Field strength as measured by the flight check receiver was expected to be correct because of its linear design.

When near a transmitter the field strength will be correct; however, the atmospheric noise measurement will indicate higher than actually exists. Hence, the SNR measurement derived from field strength and atmospheric noise will be too low. The second method to compute SNR is from phase information. This method used the jitter of the phase tracking point or the time constant required to maintain a certain phase jitter. The measurement has a resolution of 3 dB and a range from -24 to +9 dB. SNR measured by this method occurs after some clipping or limiting and perhaps additional filtering. This type of SNR measurement may report values better than actually exist. The improvement is dependent on the type of noise present and the type of limiting. According to "An Atmospheric Noise Model with Application to Low Frequency Navigation Systems" (item 23 Related Documents), improvements of up to approximately 16 dB in SNR may be experienced, depending upon the type of clipping/limiting and the type of noise. Measurement of SNR by this method may, however, be more representative of a typical MOPS receiver.

One additional factor affecting the SNR measurement is local noise which may come from precipitation static, lightning storms, and interference. During en route flights, precipitation static would buildup on the aircraft and reduce the SNR. The amount of charge build up on the aircraft is a function of the aircraft and type of weather. Problems due to weather are variable, therefore, measurements during these times may not be typical of the signal in space or even what other aircraft might see.

Measured ECD values were, in some cases, higher than theoretical values. Received ECD when in close proximity to the transmitter, but still in the far field, will generally be +2.5 microseconds with a nominal transmitter ECD of zero. Some transmitters will transmit a nominal ECD of +0.5 microseconds or +3.0 microseconds far field to increase usable range. ECD, according to theory, will decrease as a function of range. The actual rate of decrease is a function of ground conductivity and terrain. During the flight check of several airports, ECD values in excess of +3.0 microseconds were observed when near a transmitter. Lab tests with a simulator indicated the receiver occasionally estimated the actual ECD with an error of up to 0.5 microseconds.

BASELINE EXTENSIONS.

Flight near a baseline extension was a problem at Beaumont, TX. Baseline extensions cause bad geometry with degraded position accuracy and, at times, the receiver may not display a position solution. At Bedford, MA, the airport was not directly affected by the baseline extension. Aircraft approaching the airport could, however, fly across the Seneca-Nantucket baseline extension. The baseline extension starts at Nantucket and extends southeast. For aircraft with

the Loran C receiver already in the dedicated triad mode, using Nantucket as one of the secondaries, flight near the baseline may cause the receiver to stop, computing a navigation solution.

INTERFERENCE.

No interference which caused degraded performance of the Loran C receiver was noted during the flight checks. In general, the major source of interference is the low frequency (LF) communications transmitters which cover very large areas of the country. The location and frequencies are well defined. These transmitters operate near and in the Loran C band. In recent years companies which generate electrical power are sending communication signals over their powerlines. These signals also radiate. Effects of powerline carrier interference can be found in report "Powerline Carrier (PLC) Interference Tests" (item 24 Related Documents).

SHIFTS IN TD'S.

During the limited flight check program it became apparent that hard firm limits were desired on TD errors. This was especially true when static checks were conducted on the runway threshold and data were compared to current monitor data. It is not possible to set a firm limit on acceptable TD errors. The actual shift of aircraft position will be a function of gradient and crossing angle. In general, as GDOP increases, smaller variations of TD's will cause larger position shifts. The following equation can be used to convert TD variation to position variation in feet.

Northing error = A * delta TD1 + B * delta TD2
Easting error = C * delta TD1 + D * delta TD2

Calculation of parameters A, B, C, and D must be done once for each airport and triad. Methods to determine these parameters can be found in appendix A of "Loran C Signal Stability Study: St. Lawrence Seaway" (item 25 Related Documents).

APPROACH PLATE INFORMATION.

Approach plates used for the flight checks were drawn by AVN procedures specialists. The intent was to provide the flight check personnel with a pictorial representation of the procedure instead of relying solely on the printed information on Form 8260. As such, it is not a finished approach plate developed by a cartographer for use by the general public. Several problems were encountered with the approach plate and if corrected, could lead to a more effective approach plate. Waypoint resolution and format were the most common problems. The Loran C receivers are set up to accept waypoint information in degrees, minutes, and fractional minutes; not in degrees, minutes, and seconds as sometimes indicated on the approach plates. Although the MOPS requires a resolution of only 0.1 minutes, most present day receivers, including the one used for flight check, permit entering waypoint information to 0.01 minutes.

The GRI and triad required for the approach did not always appear on the approach plate. Several of the approach plates had latitudes and longitudes on the plate that did not agree with information on Form 8240-7. In addition, several of the approach plates did not include the heading or distance between waypoints for the

various flight legs. With an RNAV system, heading and distance between waypoints are a good cross-check method to insure correct waypoint information. Heading information is also very helpful (if not necessary) when turning onto a new course. Normally, heading and distance to the waypoint are published on approach plates available to the public.

Lakefront is a good example of a potential problem with the approach plate which needs to be considered. At Lakefront, the missed approach procedure is intended to be flown using a VOR. The procedure includes a turn at the missed approach waypoint. If a pilot should use the Loran C as a cross-check while executing the missed approach procedure, it will not provide the same guidance information as the VOR. At Lakefront the difference between Loran C guidance and VOR guidance could be 1 nmi.

VARIATION OF SIGNAL PARAMETERS FOR THE APPROACH.

When establishing criteria for signal-in-space it is necessary to determine normal variations in the signals. In this section results obtained during approach flights at each airport are analyzed. Variation of position errors, SNR(PH), SNR(FS), and ECD are presented in figures 6 to 9, respectively. All these figures have data plotted by segment number. A segment was defined as the interval between two waypoints. Segment 0 is that part of the approach which ends at the missed approach point (MAP). Positive segment numbers are before the MAP with negative numbers after the MAP. Segments are in order of flight. Data for each segment was statistically combined for all data in that segment. In most cases this includes three runs. Segment 0 data were used as a reference and subtracted from all other segments.

Figure 6 shows the results of positioning data defined in terms of ATE and CTE. Data presented in this figure are the absolute value of the mean plus two times the standard deviation. In effect it represents the largest position error for at least 95 percent of the data. A dashed line shows the maximum deviation from the segment 0 value. ATE varied from -161 to 494 feet and CTE varied from -279 to 481 feet.

Figure 7 shows the comparison for SNR derived from phase information. Segments are the same as in figure 6. Each airport has three values for each segment; one for the master, one for secondary one, and one for secondary two. Data presented are the mean value minus two times the standard deviation. This would be equivalent to the lowest value of SNR for 95 percent of the data. Data for segment 0 has been subtracted from each segment. Variations are within 1 dB of the segment with the MAP. Figure 8 shows the comparison for SNR derived from field strength and atmospheric noise measurements. The plot is similar to figure 7. The variation for this plot with respect to segment 0 values are -2 to +3 dB. Figure 9 shows the results from ECD data. The figure is similar to figures 6 through 8. Values are the absolute value of the mean plus 2 standard deviations. This represents the largest excursion of 95 percent of the data. Data are again referenced to segment 0. For ECD, the data varied from -0.9 to +0.5 microseconds.

As the flight checks progressed, static data were also collected. For these data the aircraft was parked on the threshold of the runway. Data collection varied from a minimum of TD and position information only, to the addition of field strength, SNR, ECD, and atmospheric noise information. Table 7 shows a comparison of the TD bias at the monitor, runway threshold, and during flight.

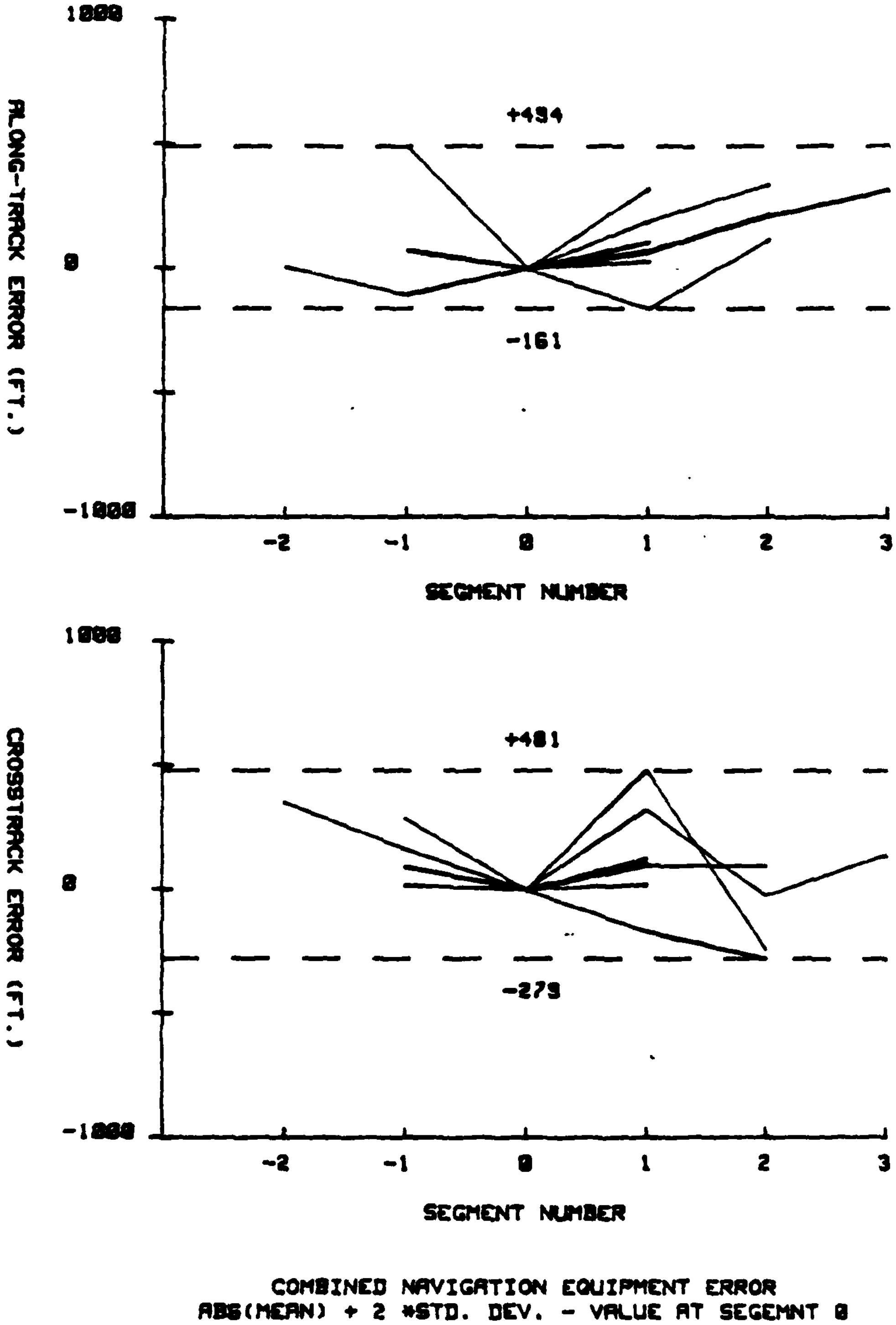
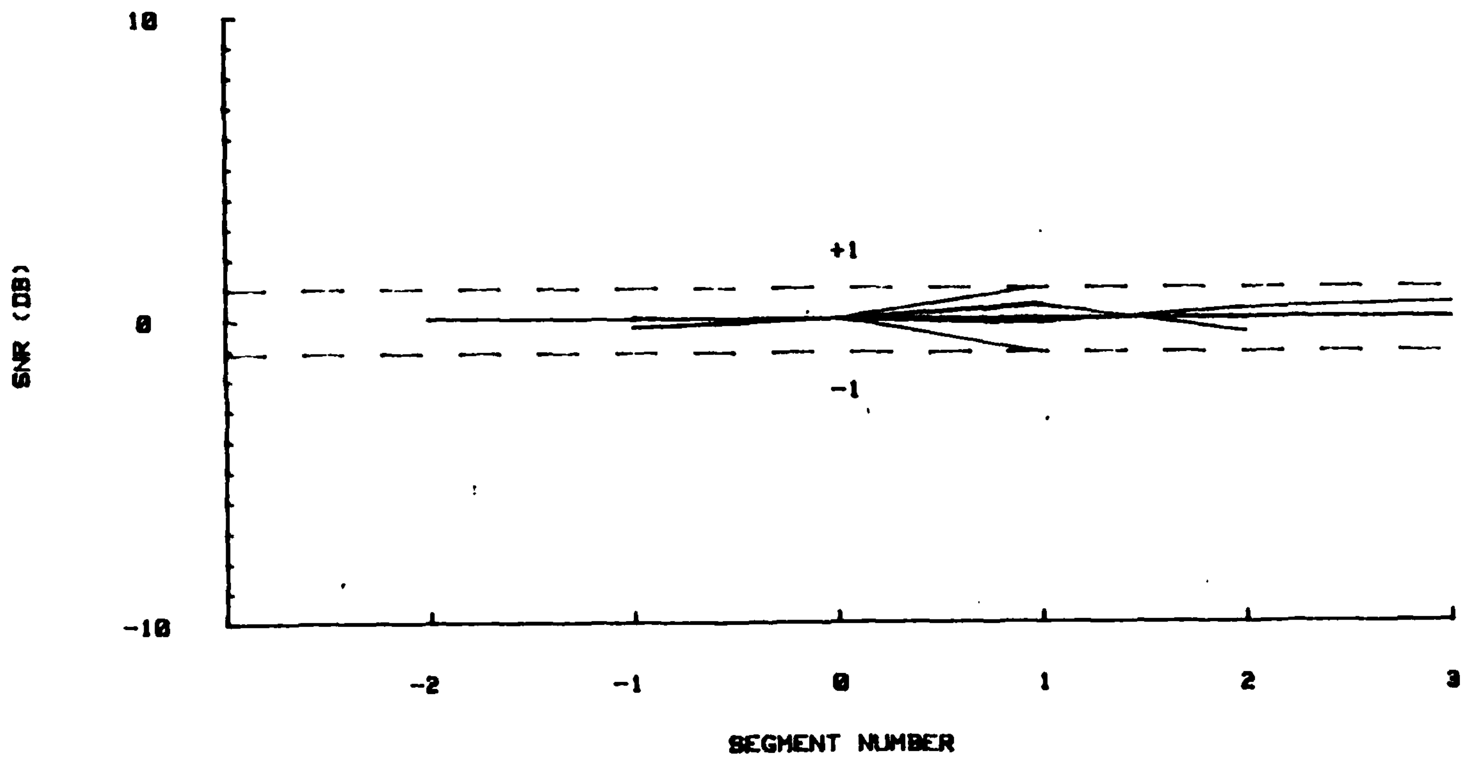
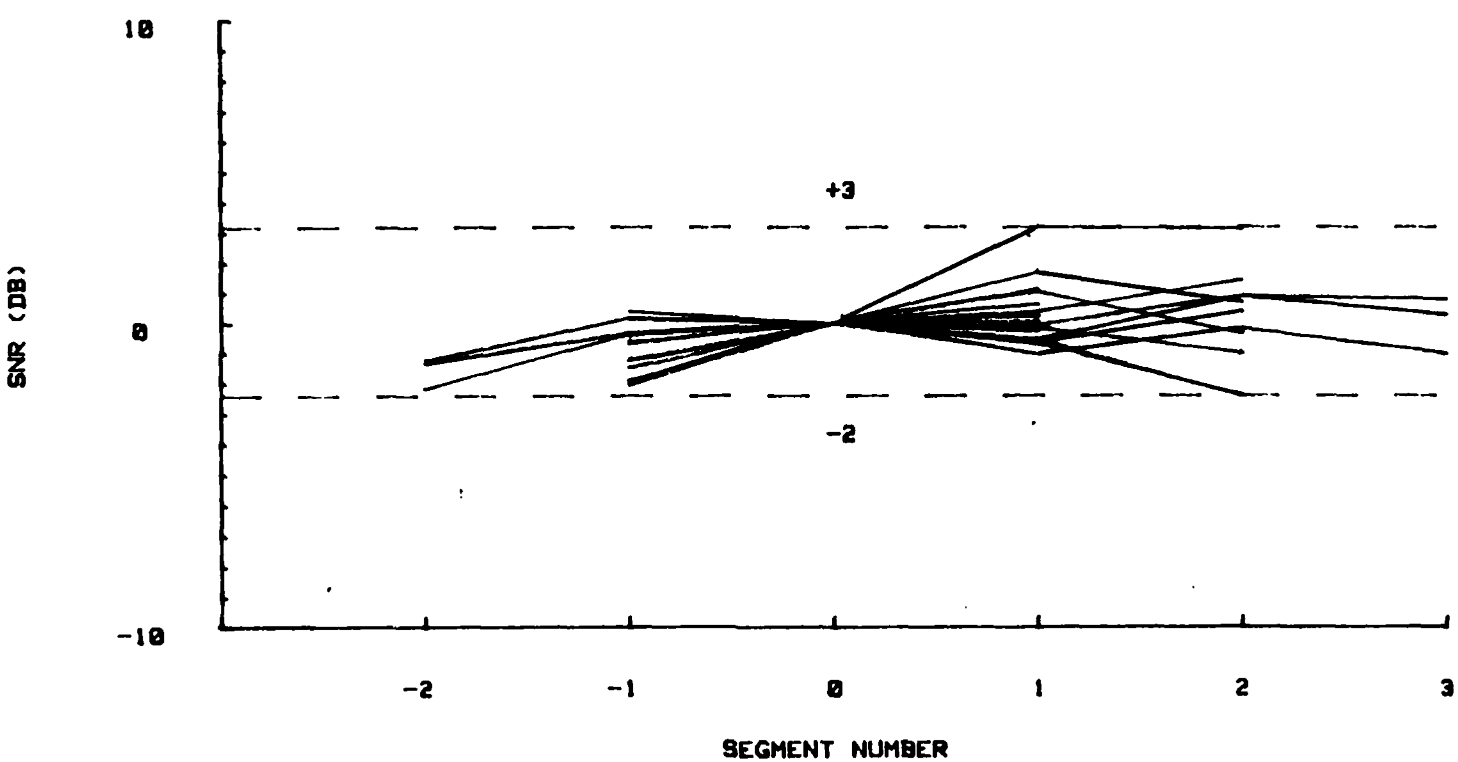


FIGURE 6. COMBINED NAVIGATION EQUIPMENT ERRORS



COMBINED SNR(PH) (MEAN - 2*STD. DEV.)
VALUE - VALUE AT SEGMENT 0

FIGURE 7. COMBINED SNR(PH)



COMBINED SNR(FS) (MEAN - 2*STD. DEV.)
VALUE - VALUE AT SEGMENT 0

FIGURE 8. COMBINED SNR(FS)

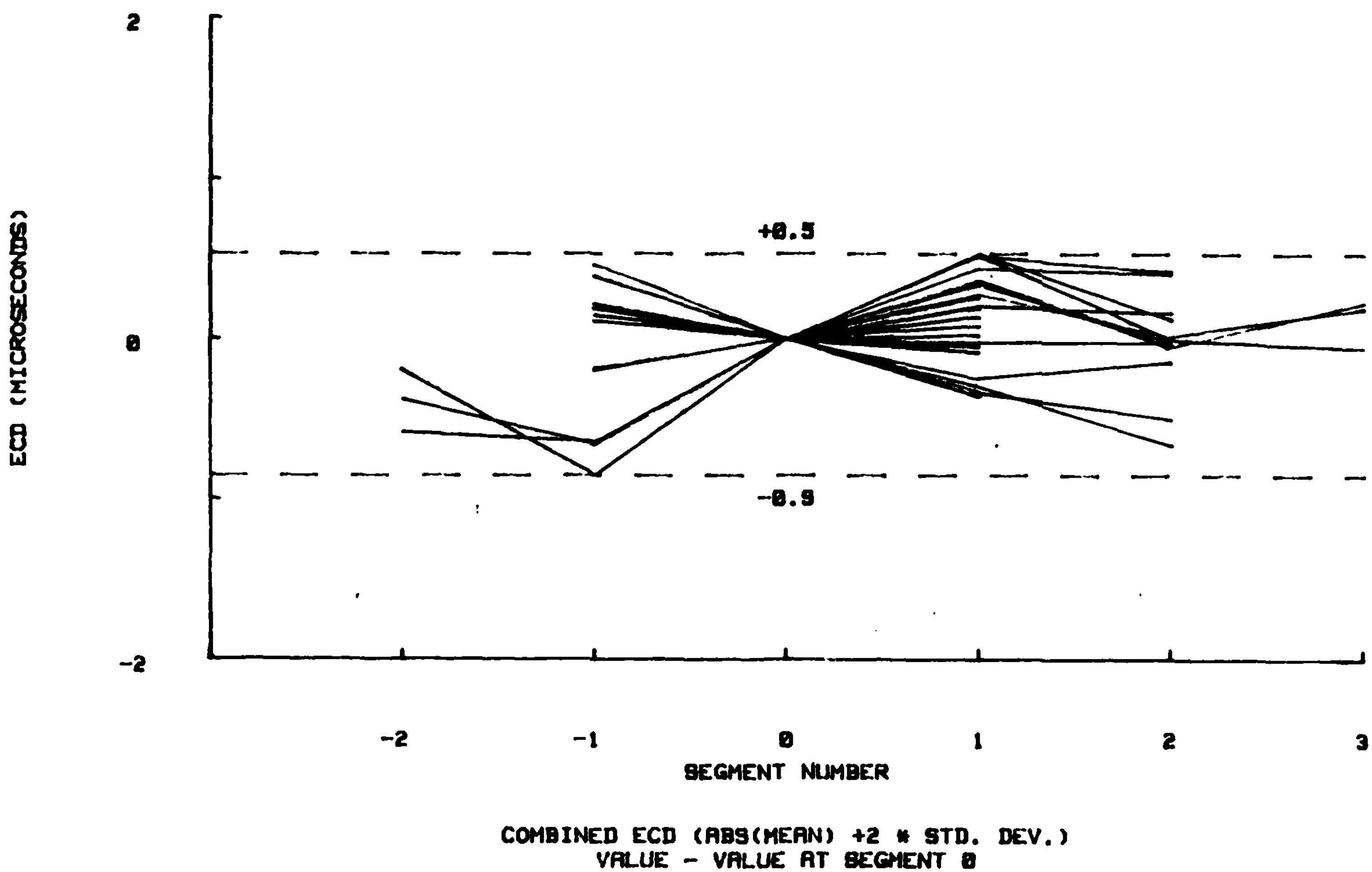


FIGURE 9. COMBINED ECD

TABLE 7. COMPARISON OF TD BIAS VALUES (MICROSECONDS)

	Airports					
Parameters	OSU	MFD	PDX	SLE	ORL	NEW
Flight Minus Monitor						
TD1	-0.44	-0.09	-0.41	0.55	0.04	-0.33
TD2	-0.49	0.70	0.11	0.19	0.49	-0.56
Threshold Minus Monitor						
TD1	-0.07	0.11	-0.08	-0.21	-0.17	0.03
TD2	0.21	0.37	0.07	0.04	-0.07	-0.18
Flight Minus Threshold						
TD1	-0.37	-0.21	-0.33	0.76	0.21	-0.36
TD2	-0.70	0.33	0.04	0.15	0.56	-0.38

Data presented in the table show the difference between TD bias values for the specific measurements noted in the table and appear in microseconds. Monitor values were the average TD bias obtained from the local area monitor during the flight tests. Static runway data were obtained from the Loran C receiver display while the aircraft was parked on the runway threshold. A single value for each parameter was recorded after allowing the receiver to settle for about 20 seconds. TD bias values for flight data were the mean of all TD bias samples taken during the three approaches conducted at that airport. Runway threshold data were collected at six airports for comparison. The airport designators appear at the top of each column. The table has three sections. The first section, "flight minus monitor," shows the difference between the flight TD bias and the monitor TD bias. Section two, "Threshold Minus Monitor," shows the difference between the TD bias at the threshold and the monitor TD bias. The third section, "Flight Minus Threshold," shows the difference between the flight TD bias and the TD bias at the threshold.

Table 8 shows the same comparison as table 7 except the difference in microseconds have been converted to feet. From table 8 it can be seen that threshold minus monitor data agreed with each other to within 185 feet. The variation includes any errors which might be present in the position of the local monitor, runway threshold, position of the aircraft with respect to the actual threshold survey point, and variation of the Loran C signal propagation. Resolution of the monitor position and runway threshold were limited to 0.01 arc minutes, the resolution of the flight check receiver. This is approximately 60 feet. Differences for flight minus threshold data were larger than for threshold minus monitor data. The largest differences were observed for flight minus monitor data. At Salem (SLE) the errors were -413 and 540 feet.

Comparisons which use TD bias from flight data have the largest errors. The results are not suprising. TD bias from flight data has error contributions from the aircraft positioning system (GPS) and flight dynamics. Appendix C of

"Loran C Nonprecision Approaches" item 2 Related Documents describes data latency for several Loran C receivers. For the ANI-7000 receiver, data latency of 0.2 to 0.7 seconds were observed in the TD measurements. Tests using the Loran C present position from the ANI-7000 uncovered a problem with the receiver which was then corrected. No further testing was performed after the correction. Position data from several other receivers were also tested. Results of these tests indicated data latency was evident and caused errors in the ATE direction. Little error was found in the CTE direction. Errors were a function of ground speed going from a low of 191 feet at 150 knots to 891 feet at 250 knots. What has been shown is that static data from the runway threshold and monitor are highly correlated.

TABLE 8. COMPARISON OF TD BIAS VALUES (FEET)

	Airports					
Parameters	OSU	MFD	PDX	SLE	ORL	NEW
Flight Minus Monitor						
North	-291	-202	220	-413	-285	-158
East	-171	437	201	540	-319	-237
Threshold Minus Monitor						
North	-79	26	15	127	-53	-177
East	135	185	157	46	67	-31
Flight Minus Threshold						
North	-213	-237	204	-541	-232	18
East	-307	257	44	494	-386	-206

Table 9 shows the ability to predict airborne Loran C equipment errors given the area calibration values used by the receiver and current TD information at the runway threshold. The first section, "Loran C Receiver Error," of the table shows the difference between the present position of the Loran C receiver using area calibration and the published position of the runway threshold. Data were collected with the aircraft parked over the runway threshold. The second section, "Error Introduced by Area Calibration Value," of the table shows the error introduced by the area calibration value entered into the receiver. This error is computed by calculating a TD bias for the area calibration value and a TD bias for the runway threshold using TD's presently measured at the runway threshold. If the two TD bias values are not identical, the Loran C present position should be in error by the difference. For analysis, the difference in TD bias has been converted to a displacement in feet. The third section shows "Difference Between Receiver and Area Calibration," the result of subtracting the error introduced by the current area calibration values from the error obtained

from the Loran C receiver. If all errors were accounted for, section three would contain all zeroes. Errors were as large as 89 feet. It is expected these errors were introduced because the monitor locations were not surveyed. The result indicates the ability to predict the errors that will be seen in the Loran C receiver's present position. All that is needed is the current area calibration values entered into the Loran C receiver and the current TD bias at the runway threshold. This method could, however, be expanded to include current TD bias obtained from the local area monitor, as shown in table 8.

TABLE 9. COMPARISON OF STATIC POSITIONING ERRORS (FEET)

	Airports					
Parameters	OSU	MFD	PDX	SLE	ORL	NEW
Loran C Receiver Error						
North	0	-122	-61	122	-122	-182
East	279	368	221	-43	53	-53
Error Introduced by Area Calibration Value						
North	-45	-149	-12	127	-97	-161
East	300	361	164	46	22	-27
Difference Between Receiver and Area Calibration						
North	45	-27	-49	-5	25	-21
East	-21	7	57	-89	31	26

The next step in the analysis would be to compare position errors from flight data with static data obtained on the runway threshold. To observe any effects of flight dynamics, the northing and easting errors shown in tables 7 to 9 were replaced with ATE and CTE. The comparison appears in table 10. Section one of the table shows ATE and CTE obtained from flight data. Data are presented for the same six airports. A positive ATE means the Loran C reported a position ahead of the position reference system. A positive CTE means the Loran C reported a position to the left of the position reference system. Static runway data which appeared in table 9 has been rotated from northing and easting errors into ATE and CTE using the runway heading for the airport. These data appear in section two. The third section is the difference between flight data and static data. For each airport the ATE values are larger than the CTE values. This suggests a lag in the system. In general, CTE values were small except for Ohio State (OSU). The source of the larger CTE was investigated but could not be found.

TABLE 10. COMPARISON OF STATIC AND FLIGHT TEST (FEET)

	Airports					
Parameters	OSU	MFD	PDX	SLE	ORL	NEW
Flight Data						
ATE	145	-502	-126	-295	-214	108
CTE	-226	-162	220	-148	-182	-138
Static Data						
ATE	279	-338	223	122	-1	182
CTE	-17	-191	54	-43	-133	-55
Difference						
ATE	-134	-164	-349	-417	-213	-74
CTE	-209	29	166	-105	-49	-83

VARIATION OF SIGNAL PARAMETERS FOR THE BOX PATTERN.

In this section Loran C signal parameter variation during the box pattern flights were analyzed. Due to the low frequency of Loran C, little variation of SNR or ECD were expected over the area of the box pattern. Theoretical data from "Loran C System Characterization" (item 26 Related Documents) shows the attenuation rate of Loran C signals are a function of the propagation path and the distance from the transmitter. Assuming a homogenous seawater path, the attenuation rate at a distance of 100 nmi from the transmitter is 7 dB/100 nmi and changes to 4 dB/100 nmi at a distance of 900 nmi. The attenuation rate is the smallest for a seawater path. The highest attenuation rate would be experienced for an all glacial ice path. For practical purposes the attenuation rate for poor rocky soil would be the worst experienced in the continental United States. If the path was changed to all poor rocky soil, the attenuation rates would change from 11 dB/ 100 nmi at a distance of 100 nmi from the transmitter to 7 dB/100 nmi at a distance of 900 nmi. In the real world the path between the transmitter and the receiver is not homogenous, therefore, the actual attenuation rates should be between these two conditions. Field strength changes of only 0.4 to 3 dB would be expected over a 20 nmi area around an airport. ECD, according to theory, changes at a rate of 0.0025 microseconds per nmi for an all seawater path. This would be 0.05 microseconds for a 20 nmi area around the airport.

Bedford, MA, is a good place to show the effect of the propagation path. Figure 10 shows the Loran C parameters for station W (Caribou) from the box pattern flights. Field strength varied by approximately 10 dB over the box pattern. Distance to Caribou changed by approximately 40 nmi over the entire box

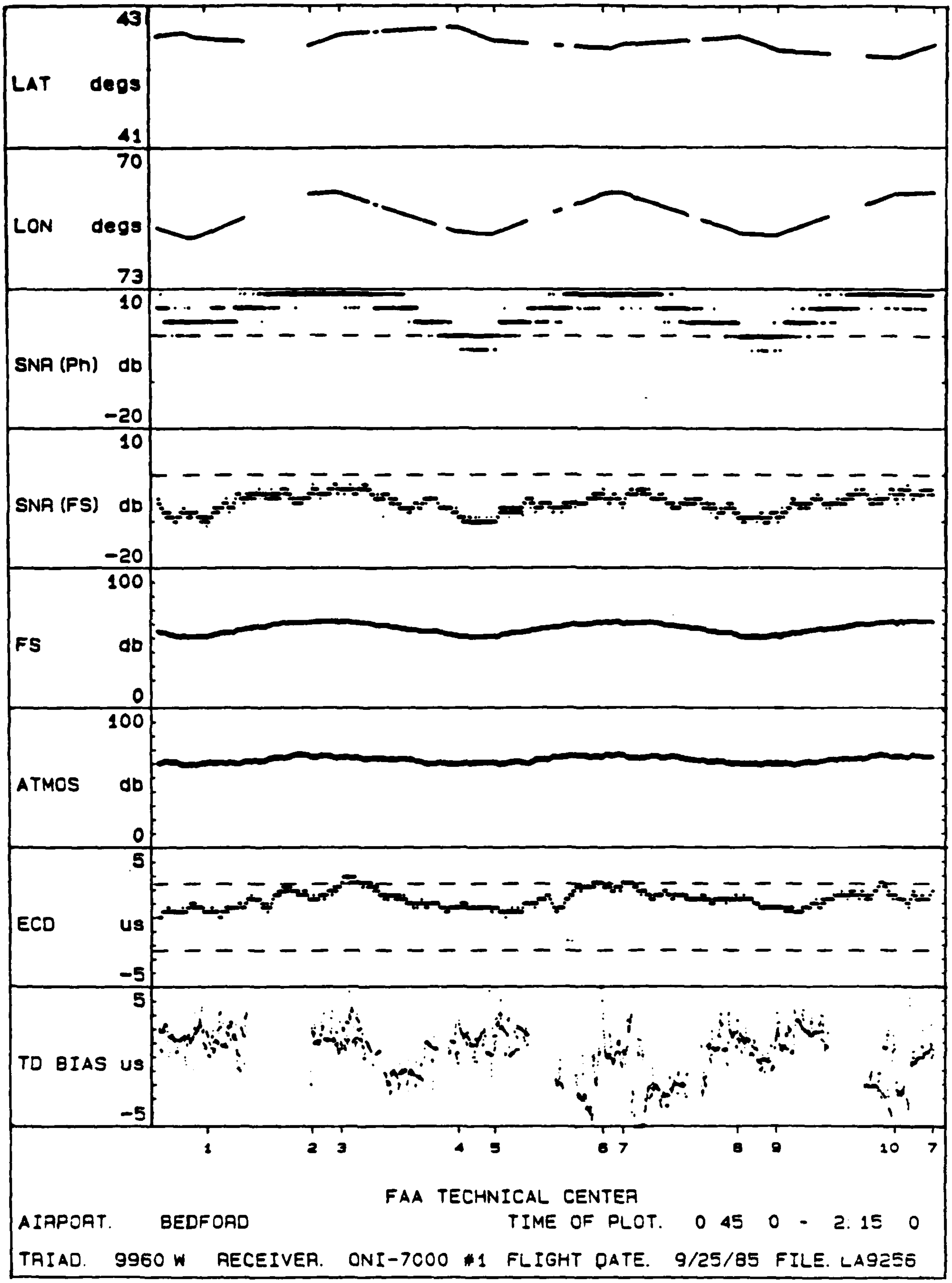


FIGURE 10. LORAN C PARAMETERS FOR STATION W (CARIBOU)

pattern. If the path between the transmitter and receiver is assumed to be poor rocky soil, a variation of only 3 dB would be expected due to the change in distance. If an all seawater path were assumed, the variation would be even less. Figure 11 is a map of the area. On the map is the location of the transmitter at Caribou and the box around Bedford. As shown on the map by the heavy line from Caribou, the western part of the box receives signals from an all land path, while the eastern part of the box receives signals from a mixed land and seawater path. If the path between the transmitter and Bedford is assumed to be an all seawater path and compared to the land path, a change of 10 dB would occur. Therefore, it is reasonable to attribute the change in SNR to the propagation path.

Field strength data for the Master (Seneca) was constant. Figure 12 shows the Loran C parameters for station X (Nantucket). Field strength data for station X (Nantucket) is shown to vary 6 dB. The distance from the various points on the box to Nantucket varied by about 25 nmi. Variation of field strength due to changes in distance to transmitter could only account for about 3 dB. Figure 13 shows a map of the area. The western end of the box pattern receives signals from Nantucket over a constant mixed land and sea path. The eastern end of the box receives signals over a mixed land and sea path, however, the sea path is much longer. The change in conductivities might account for the changes in field strength.

Figure 14 shows the effect of atmospheric noise on SNR. Data are from flights at Orlando, FL. SNR from phase information is in excess of 9 dB, the maximum value measured by the receiver. SNR from field strength and atmospheric noise shows a variation of over 10 dB. The variation of the field strength is very small. Comparison of the atmospheric noise with SNR(FS) shows the variations to be very similar (note change in scaling).

The difficulties experienced with flying the box pattern were not apparent. Figure 15 shows the box pattern flown for Portland, OR, on one of the earlier flights and what can happen. The mixed up pattern was caused by a lack of a standardized procedure and lack of bearing for each leg of the box. Future box patterns were standardized and resulted in good patterns. An example of what can be done appears in figure 3. The standardization included starting on the approach procedure, continuing 10 nmi past the last waypoint on the procedure, making all left turns. The sequence was to fly the approach procedure, 10 nmi left of the approach, 10 nmi right of approach, 2 nmi left of approach, and then 2 nmi right of course. This sequence made no leg shorter than 4 nmi long.

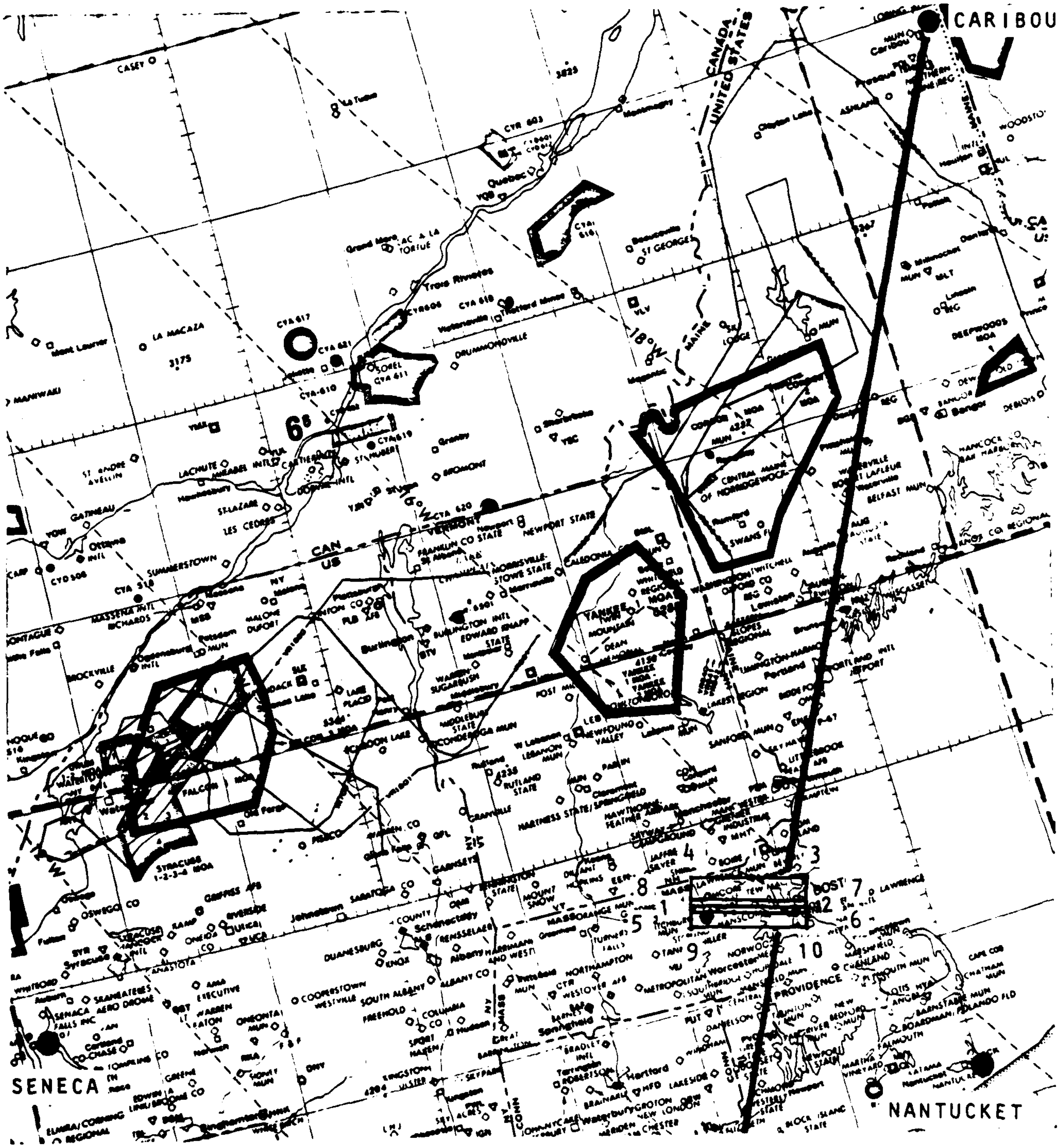


FIGURE 11. MAP OF AREA FOR CARIBOU

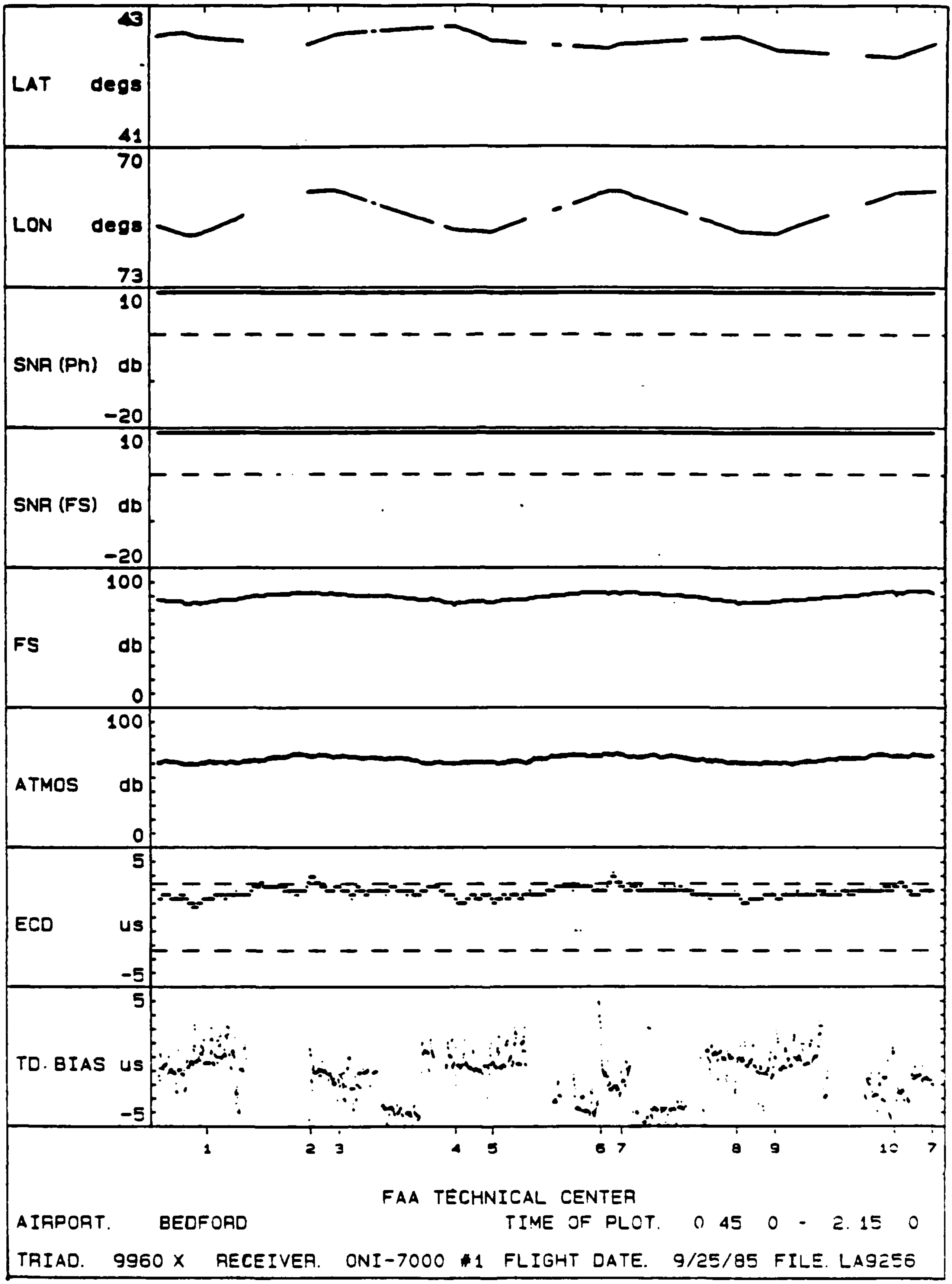


FIGURE 12. LORAN C PARAMETERS FOR STATION X (NANTUCKET)

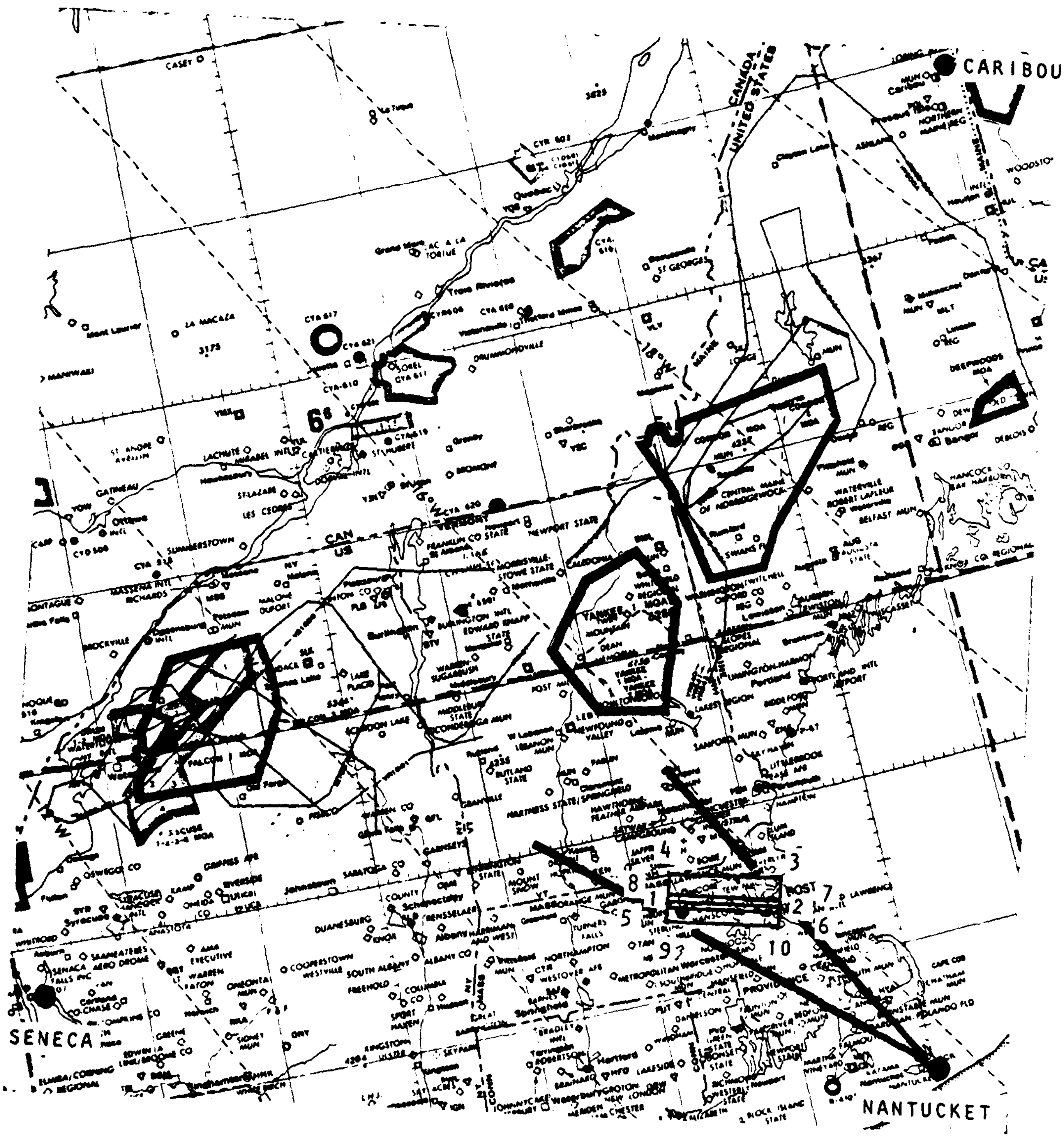


FIGURE 13. MAP OF AREA FOR NANTUCKET

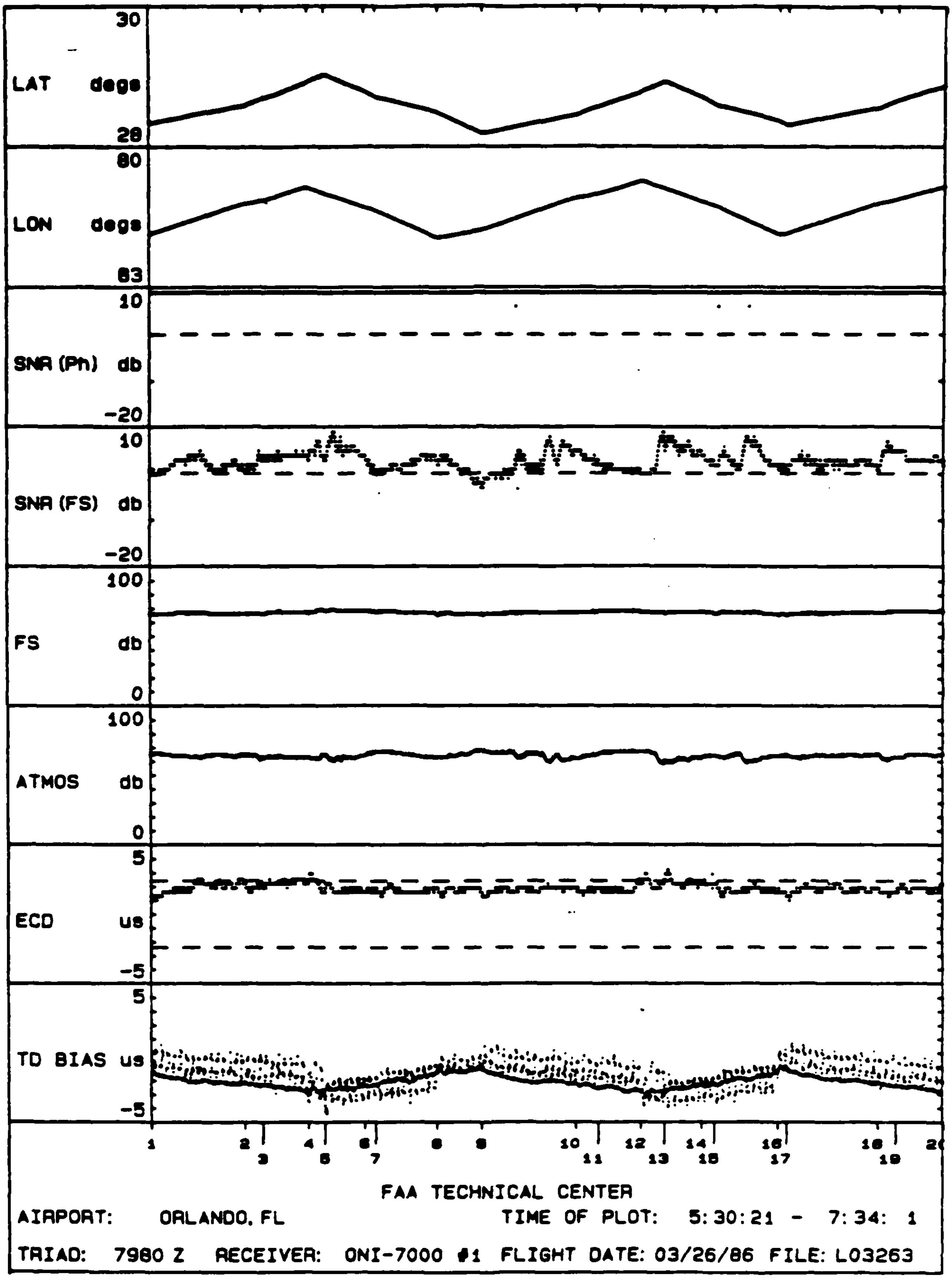


FIGURE 14. LORAN C PARAMETERS FOR STATION Z (CAROLINA BEACH)

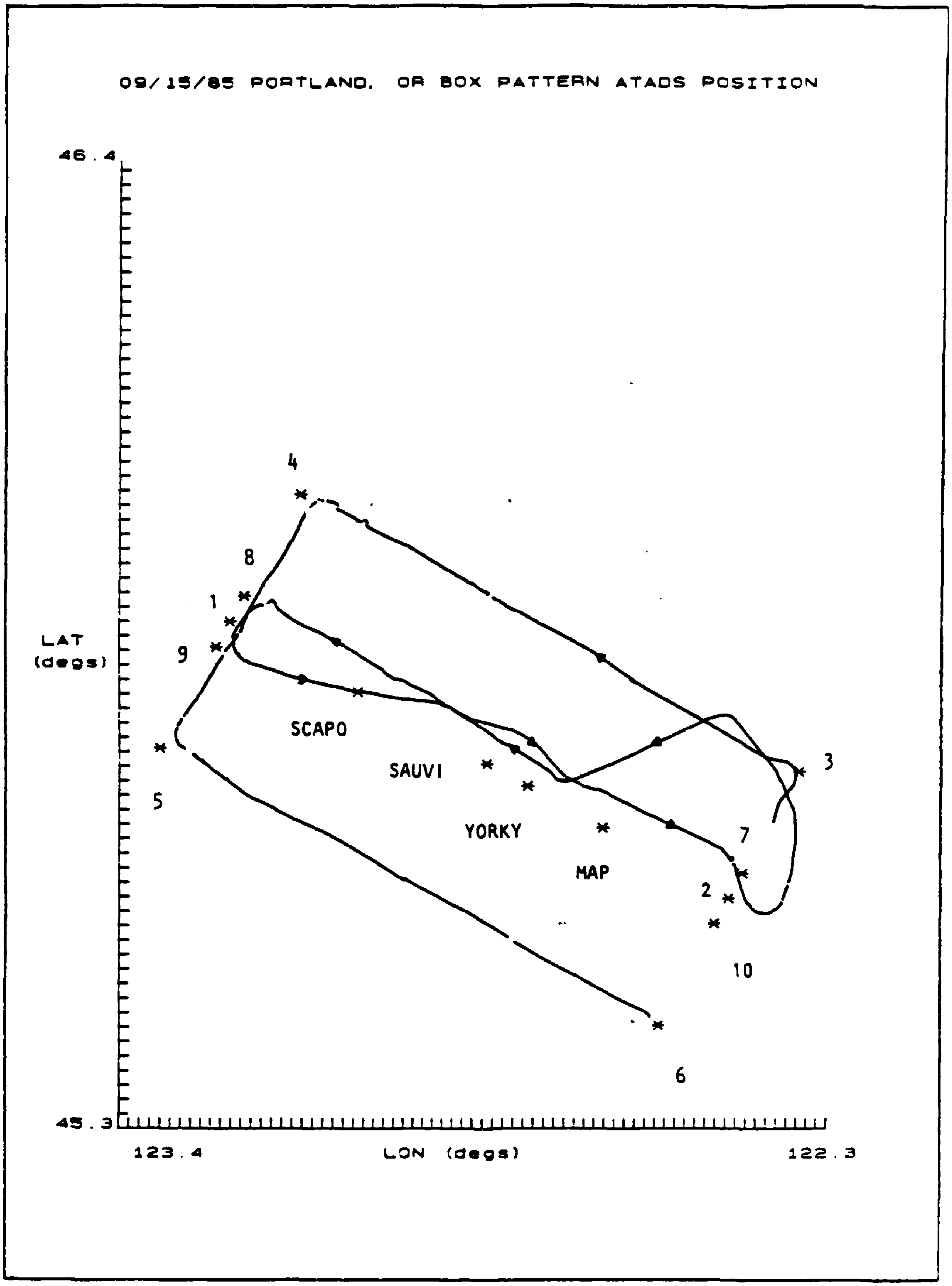


FIGURE 15. AIRCRAFT POSITION FOR BOX PATTERN (PORTLAND)

CONCLUSIONS

1. Loran C approach procedures using time difference (TD) corrections can be overlaid over existing approach procedures, e.g., localizer and very high frequency omnidirectonal range (VOR).

2. All users must use the same geodetic datum.

3. Incorrect TD calibration information increased Loran C position error and caused many flight checks to be repeated. The incorrect TD calibration information was caused by one or more of the following: incorrect monitor location, wrong monitor TD's, and mixed geodetic datums.

4. The MITRE Airport Screening Model is inconsistent with the Defense Mapping Agency (DMA) seawater model specified in the Loran C Minimum Operational Performance Standard (MOPS).

5. TD bias data from the monitor and runway threshold determined from ground tests agreed to within 185 feet for six of the eight airports. Static data were not recorded at two airports.

6. Flight data indicated receiver position lags were predominant primarily in along-track error.

7. Airborne equipment errors can be predicted using the published TD bias and the current TD's at the monitor.

8. Accurate measurement of TD bias (less than 0.5 microseconds) could not be determined with flight data because of uncertainty in the time of validity of the receiver data and the accuracy of the reference position. These effects are position dependent and cause the TD bias error to increase as geometric dilution of precision (GDOP) decreases.

9. The flight check receiver used for these tests did not permit entering delta TD corrections as specified in the MOPS. Area calibration was mechanized in the receiver using the position of the monitor and published TD's. This method operated satisfactorily at the eight airports.

10. Spring seasonal flight checks reported elsewhere and referenced in this report were conducted with a test version of software that permitted entering delta TD corrections. The tests uncovered inconsistencies with the published TD corrections (incorrect seawater model) and the implementation of delta TD corrections in the flight check receiver. The flight check receiver did not work correctly at New Orleans, LA. The problem appears to be an error in the receiver propagation equations for distances less than 86 miles from a transmitter.

11. Envelope-to-cycle difference (ECD) variation was between -0.9 and 0.5 microseconds for all approaches.

12. There appears to be an ECD measurement deficiency in the flight inspection receiver, hence, the validity of ECD measurements are suspect. Simulation tests indicate the ECD measurement uncertainty is ± 0.5 microseconds.

13. Signal-to-noise ratio (SNR) varied 3 decibel (dB) over the approach (95 percent probability).

14. SNR can be measured from phase information (SNR(PH)) and field strength and atmospheric noise (SNR(FS)).

15. SNR(PH) measurements from the flight inspection receiver is deficient in the ability to resolve measurements to less than 3 dB.

16. SNR(FS) as measured from the flight inspection receiver is inaccurate (estimates too low) because of an incorrect noise measurement when near a Loran C transmitter.

17. No detrimental effects were observed from interference. The three automatically tuned notch filters were sufficient to eliminate possible interference from low frequency communication transmitters and other sources.

18. The range of GDOP at the airports approved for the limited implementaion program was 956 feet/microsecond at Bedford, MA, to 2603 feet/microsecond at Portland, OR. GDOP at Beaumont, TX, was 8999 feet/microseond which proved to be unacceptable.

19. The full capability of random area navigation (RNAV) approaches have not been utilized in the limited implementation program. Pilot workload was high due to the number of waypoints for an approach.

20. A commissioning flight check is necessary to validate the procedure, the TD corrections, and signal-in-space characteristics.

21. Large fluctuations of the Loran C signal-in-space, which the ground monitor or static tests on the runway threshold cannot indicate, may exist around some airports because of changes in the signal propagation path, as evidenced at Bedford, MA.

22. Navigation to the approach procedure may overfly a baseline extension (approaching Bedford, MA, from the east) or a Loran C transmitter. This can result in increased position errors or navigation warning flags as observed at Beaumont, TX.

23. All airports did not meet the initial signal-in-space criteria for GDOP, SNR, and ECD. However, the eight airports approved did meet the SNR and ECD criteria specified in the final draft version of the MOPS.

RECOMMENDATIONS

The establishment of flight check requirements for Loran C nonprecision approaches must be derived from a technical understanding of Loran C. Setting of specific limits for the various Loran C parameters must also be derived from the requirements of a minimum certifiable Loran C nonprecision approach receiver. The Radio Technical Commission for Aeronautics (RTCA) has developed a Minimum Operational Performance Specification (MOPS) for Loran C receivers. The Federal Aviation Administration (FAA) has not offically designated this document for

certification of receivers, therefore, it must be used cautiously. Flight check procedures should guarantee an approach will have the necessary signals-in-space for a certified Loran C receiver to function properly.

. The following recommendations cover many areas. Many of the items are beyond the scope of flight inspection criteria but will affect the accuracy or integrity of the approach and, therefore, need to be addressed. Methodologies for implementing many of the recommendations are currently being investigated by APM-420. Since Loran C is just becoming operational, experience may indicate changes are necessary. It is recommended that:

1. The position of the local area Loran C monitor antenna should be surveyed for future installations.

2. The MITRE Airport Screening Model should be updated to be consistent with the DMA Seawater model specified in the Loran C MOPS.

3. Until everyone uses the same geodetic datum, model time differences (TD's) for each monitor should be computed using the geodetic position of the monitor in North American Datum (NAD)-27 coordinates and the propagation model specified in the Loran C MOPS. All waypoints should be in NAD-27 coordinates.

4. An independent method should be used to validate the monitor installation. The method should evaluate the correctness of monitor measured TD's, signal-to-noise ratio (SNR), and envelope-to-cycle difference (ECD). This method should also include the validation of the calculated TD bias corrections.

5. Because the monitor will not always be located in the vicinity of the airport, the monitor SNR, ECD, and TD bias corrections should be evaluated for applicability to that airport.

6. A position reference system is necessary to evaluate Loran C nonprecision approach performance. Acceptable means for a position reference would be a localizer, a very high frequency omnidirectional range (VOR) when in close proximity, a frequently corrected Inertial Navigation System (INS), or a Global Positioning System (GPS) receiver. This is to insure that propagation path anomalies or local interference do not perturb the Loran C signal-in-space. The reference is not required for the coverage (box) pattern.

7. The Loran C receiver used during the limited implementation program was deficient in several catagories because the receiver was not designed as a flight inspection receiver. The deficiencies included the measurement of SNR (atmospheric noise component) and ECD as well as the implementation of TD bias corrections. These deficiencies must be corrected.

8. Until the deficiencies with the flight inspection receiver are resolved the following signal-in-space measurements techniques are recommended.

a. SNR, field strength (SNR(FS)) should be used as an indication of the SNR measurement unless in the close proximity of a Loran C transmitter. An indication of this effect is when the SNR, phase information (SNR(PH)) measurement is high and the SNR(FS) measurement is low.

b. ECD measurements from a Loran C transmitter greater than +3.0 microseconds should be ignored when near that transmitter.

9. The flight inspection and ground monitor receivers should be calibrated with respect to field strength, noise, SNR, and ECD. Calibration methods should be traceable to a known standard. One area that should be addressed is the effect of notch filters on the measurement of noise and ECD.

10. Installation of the flight check receiver in the aircraft should be validated with respect to antenna patterns, noise, and data latency.

11. Candidate airports for nonprecision approaches should be evaluated using an airport screening model prior to procedure development. Criteria to be examined should be predicted GDOP, SNR, and ECD. Evaluation should include determining the effect of proximity to baseline extensions and Loran C transmitters.

12. A commissioning flight check should include the following:

a. The approach procedure should be validated for flyability, correct waypoints, accuracy, obstruction clearances, signal interference, and communications.

b. All segments of the approach procedure should be flown.

c. A coverage pattern should be flown around the approach procedure. It is recommended the coverage pattern extend 10 miles beyond the waypoints specified in the approach procedure including holding patterns.

d. The procedure should be flown using published TD's and waypoints inserted in the flight check receiver to a resolution of 0.1 minutes.

e. Flight data on the approach should be compared with the ground monitor. The parameters compared should include SNR, ECD, and TD bias. The procedure should not be approved if the data cannot be correlated.

13. Periodic flight checks at airports without a monitor should be conducted quarterly. The methodology should be the same as the commissioning flight check but coverage patterns are not required. If the quarterly flight check data correlates with the monitor data over 1 year, periodic checks can be reduced to annual checks.

14. Only annual flight checks are required at airports with a monitor. Coverage patterns are not required annually.

15. The following processing and filtering is recommended for the existing Loran C receiver (ANI-7000) used during the limited implementation program on flight checks.

a. Use the internally filtered data from the flight inspection receiver. No additonal filtering is recomended.

b. If SNR or ECD measurements exceed the established limits for intervals greater than or equal to 10 seconds in the coverage or approach tests, the approach should not be approved if the condition is repeatable. This is to insure the user receiver can reliably detect blink and outages.

16. The following limits based on the MOPS are recommended for certification of a Loran C nonprecision approach.

GDOP	Less than 3000 feet/microsecond
ECD	-2.4 to 3.0 microseconds
SNR	Greater than -6 dB
Interference	Requires additional investigation

17. SNR is a dynamic measurement that changes with time of day and season, therefore, flight check SNR measurements that are made over a limited interval may not indicate if the limit will be exceeded. Conversely, a one time measurement may inhibit use of an airport that meets criteria most of the time. This area needs futher investigation. Possible approaches are to put portable monitors at airports without monitors or require SNR detection limit warnings in airborne receivers.

18. It is recommended the number of waypoints in the approach procedure be reduced to take advantage of the RNAV capability of Loran C.

19. It is recommended a spectrum analyzer be used to evaluate signal interference on the approaches.

20. Validation of the seawater propagation model used by Loran C receivers in the approach mode should be required for a Technical Standard Order (TSO). The validation shall demonstrate that the receiver operates properly at distance less than and greater than 86 nmi from a Loran C transmitter.

APPENDIX A

APPROACH PLATES

Appendix A contains the Loran C nonprecision approach plates used to flight check the airports in this project. The approach plates were designed by the Aviation Standards National Field Office (AVN). Approach plates were designed to overlay existing landing aids as required for the joint Federal Aviation Administration (FAA)/National Association of State Aviation Officials (NASAO) limited implementation program.

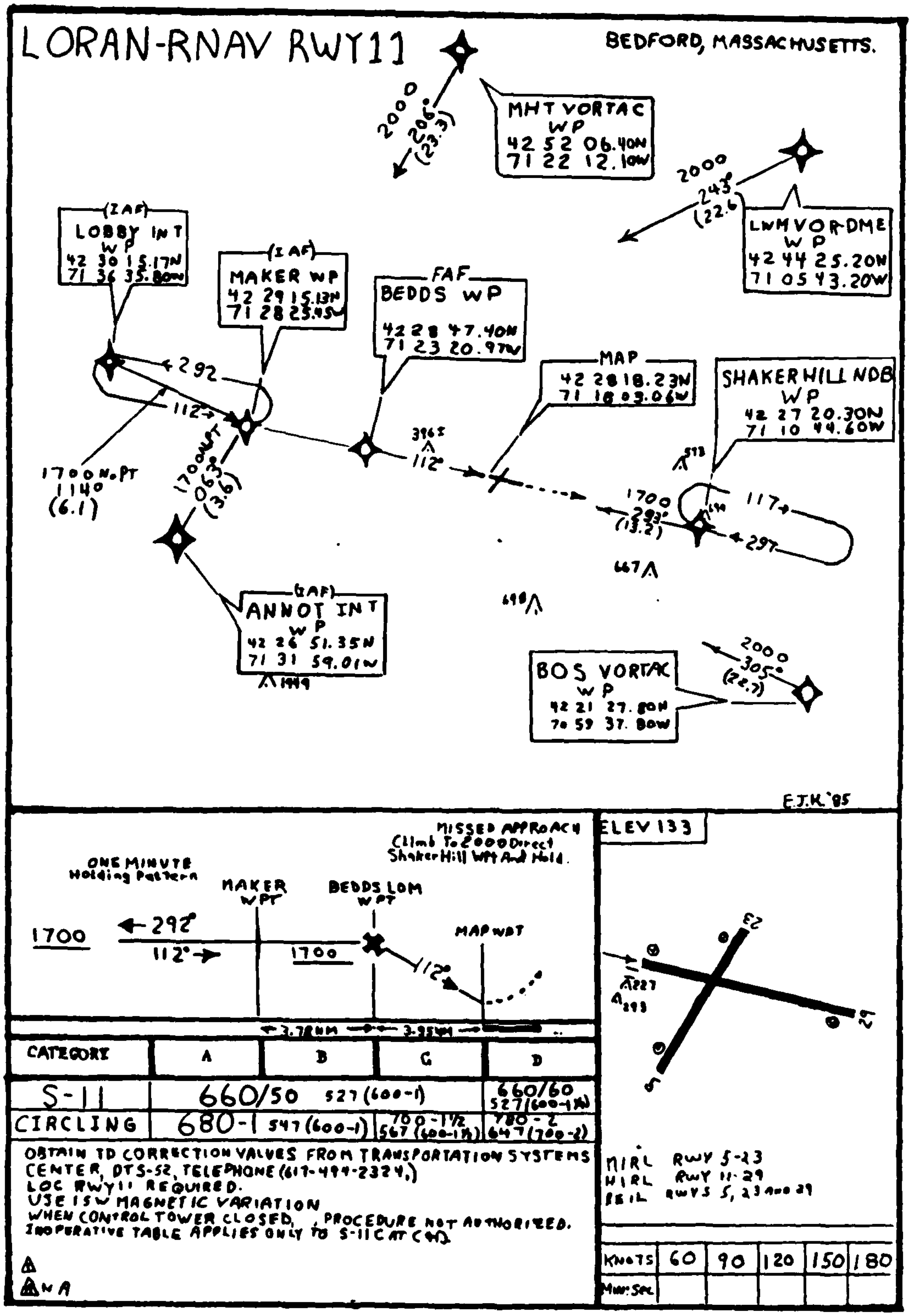


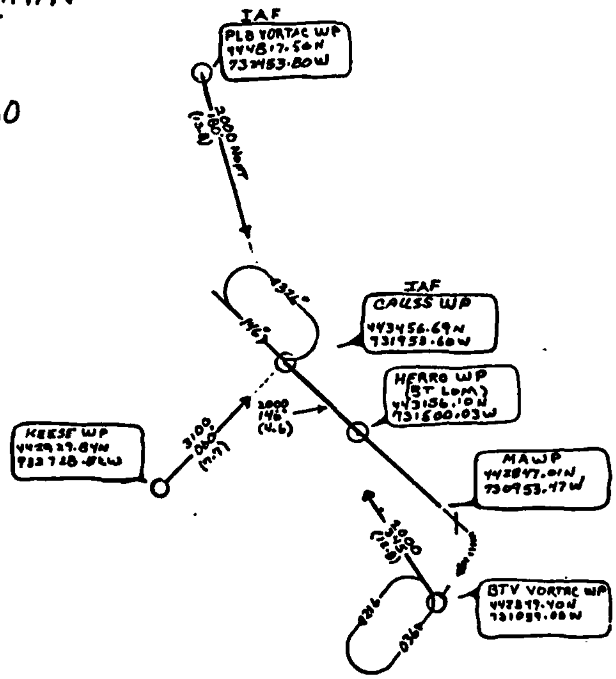
FIGURE A-1. APPROACH PLATE FOR BEDFORD

PART E- INSTRUMENT APPROACH PROCEDURE

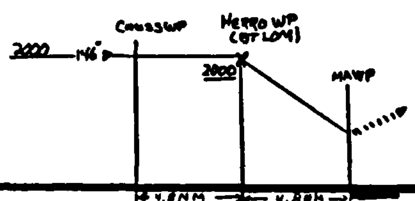
BURLINGTON INTL, VT

LORAN RNAV RWY 15

MWX 9960



CAUTION: Hi Terrain east Through south within 3 NM.
use 15 W magnetic variation



MISSED APPROACH
Climb To 1000 Then climbing right Turn To 2700 direct BTV VORTAC WP and hold.

ELEV 334

CATEGORY	A	B	C	D
S-15	800/24 473		800/40 473	800/50 473
Circling	860-1 526		860-1½ 526	1000-2 666

ASR
LOC Rwy 15 Required
Obtain TD correction values from Transportation Systems Center, DTS-52, Telephone (617) 494-2324

FIGURE A-2. APPROACH PLATE FOR BURLINGTON

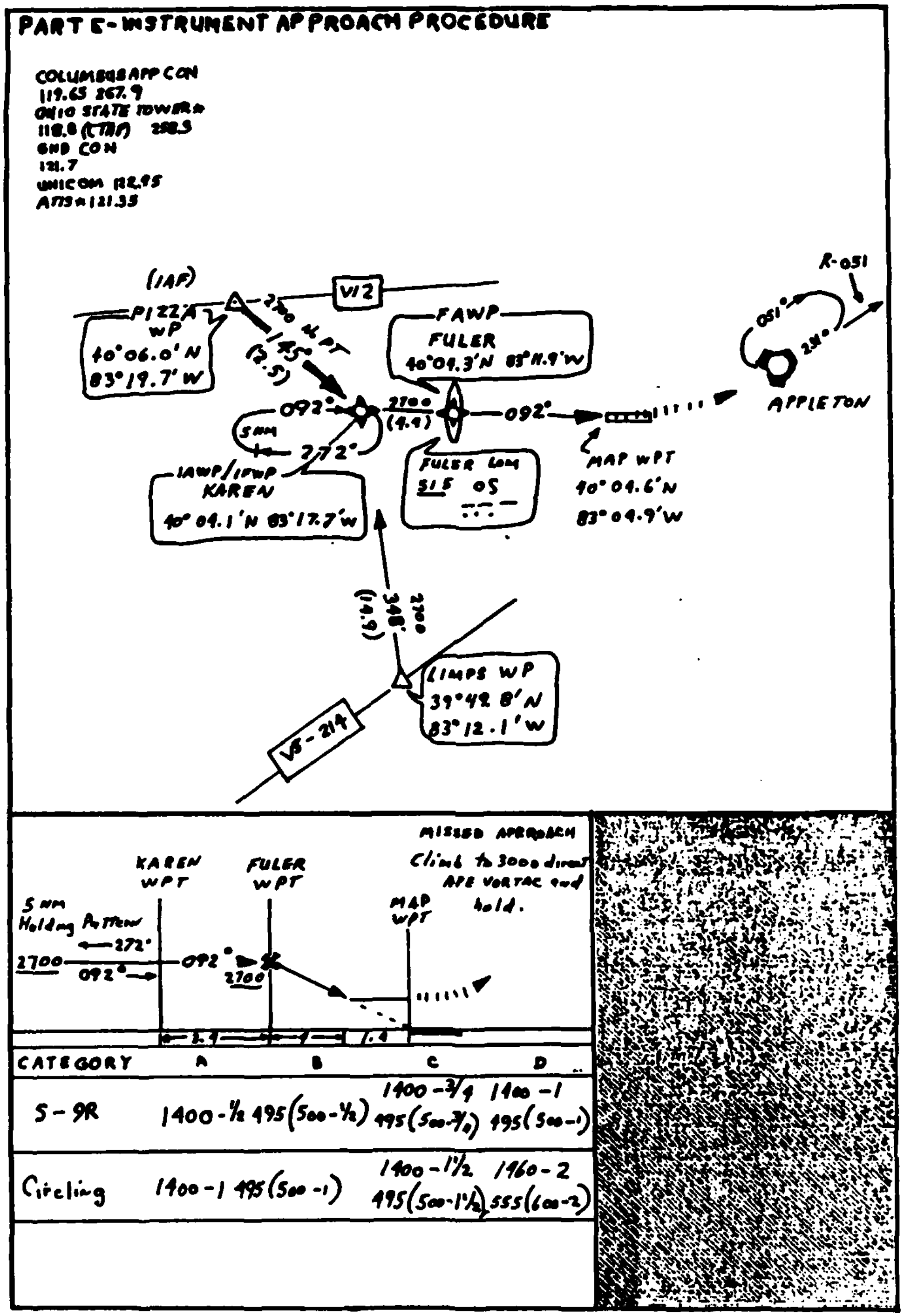
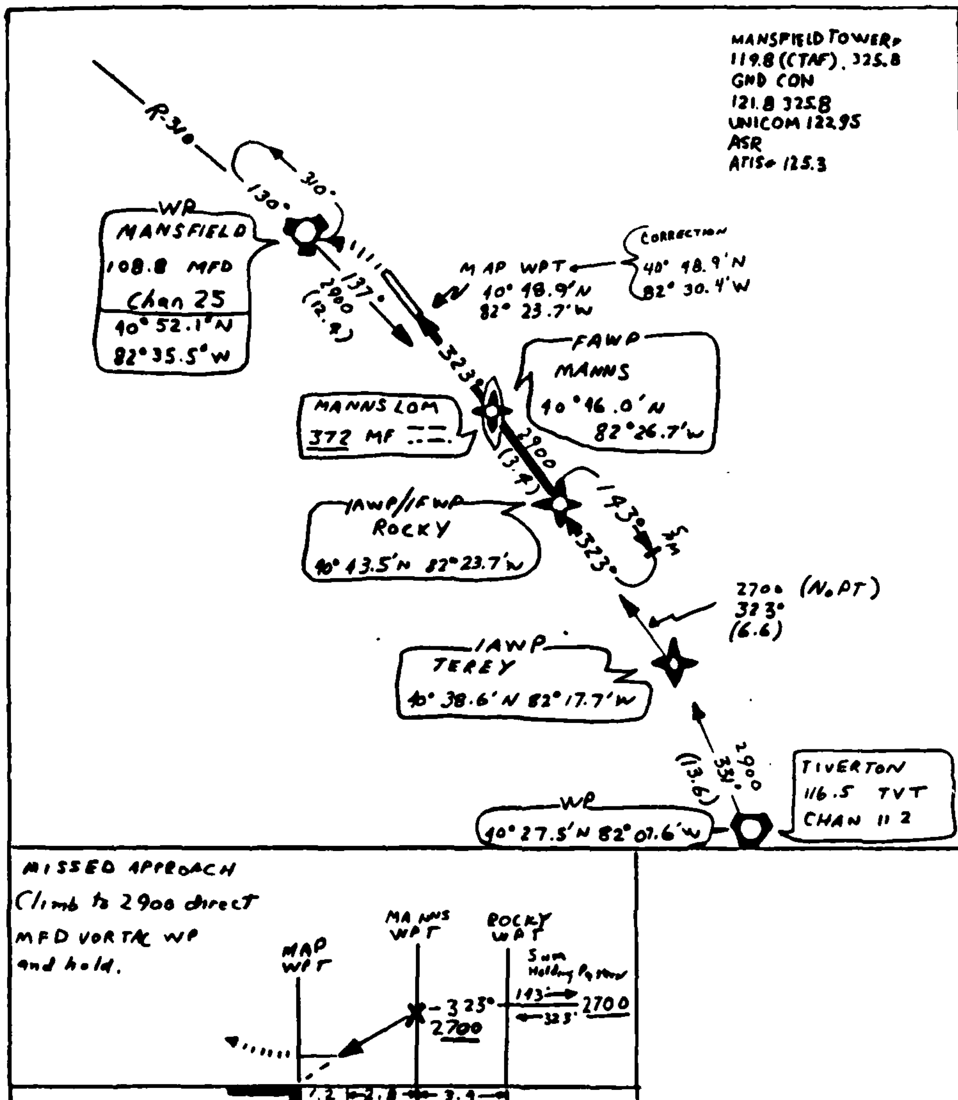


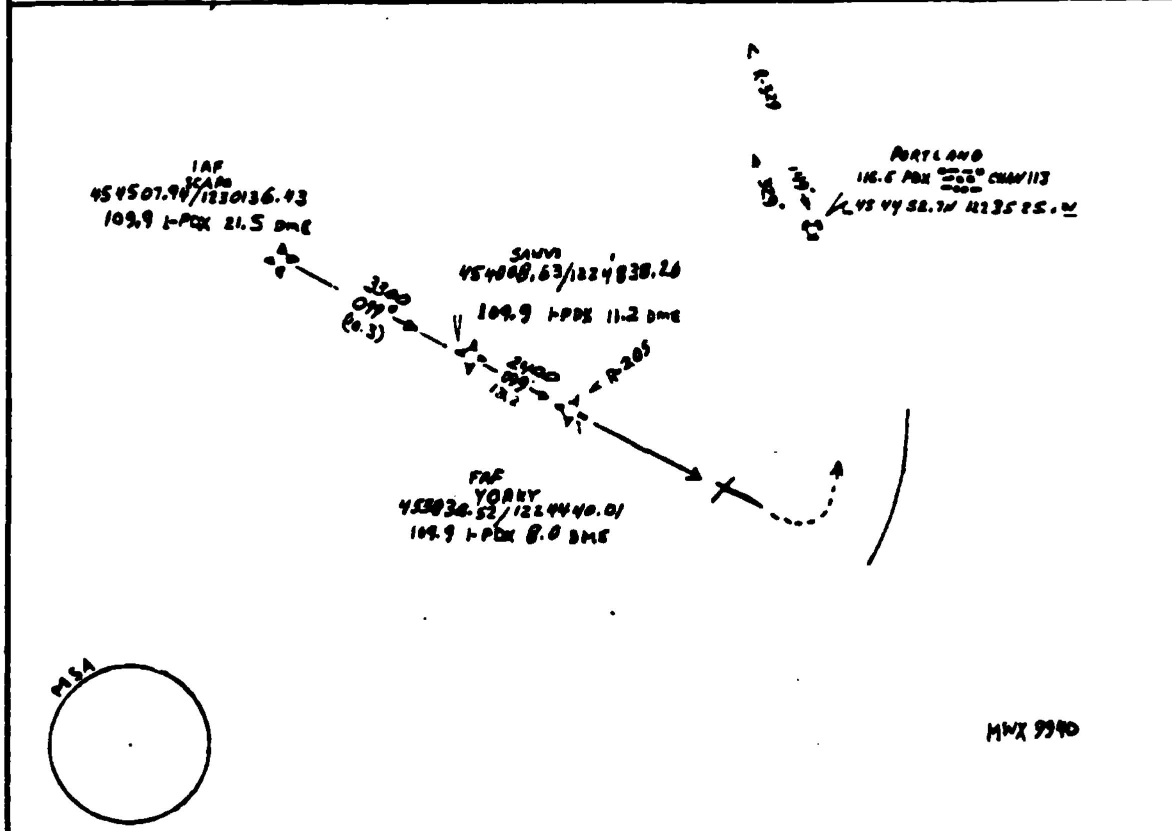
FIGURE A-3. APPROACH PLATE FOR COLUMBUS/OHIO STATE UNIVERSITY

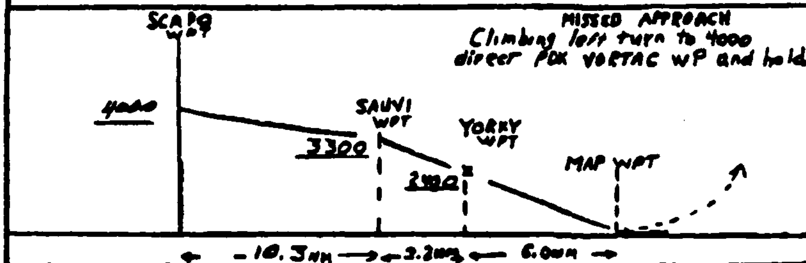


CATEGORY	A	B	C	D
S-32	1760/24 497 (500-½)		1760/40 467 (500-¾)	1760/50 467 (500-1)
Circling	1760-1 463 (500-1)		1760-1½ 463 (500-1½)	1860-2 563 (600-2)

FIGURE A-4. APPROACH PLATE FOR MANSFIELD, OHIO

PORTLAND, OR LORAN RNAV RWY 10R ORIG





ELEV 26 TDZE 20

CAT	A	B	C	D
S-	900/24	900/40	900-2	900-2 1/4
Circling	900-1	900-1 1/4	900-2 1/2	980-3

Obtain TD Correction values from Transportation Systems Center Telephone (617) 494-2324
Loc RWY 10R required.
Use 20E magnetic variation

FIGURE A-5. APPROACH PLATE FOR PORTLAND

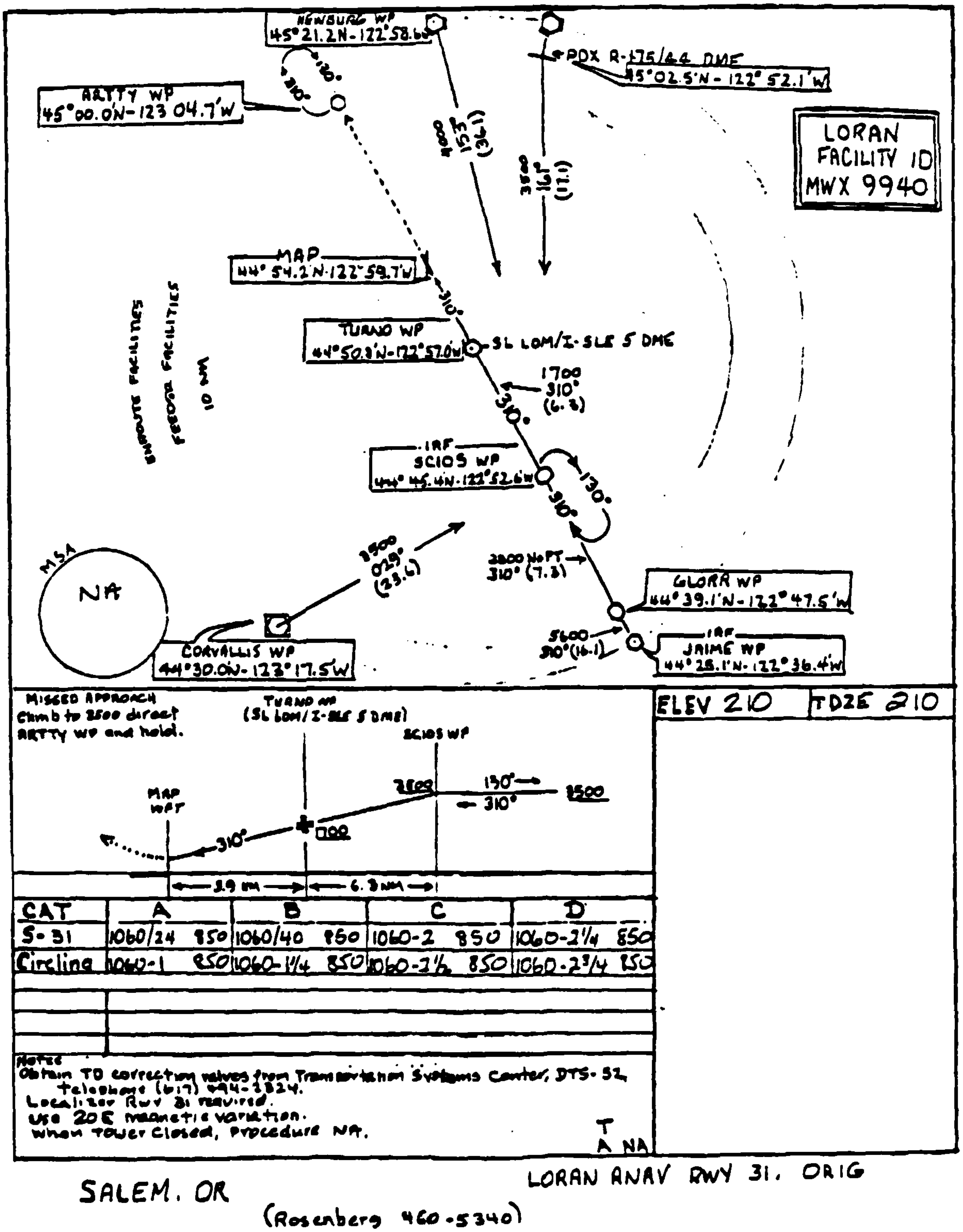


FIGURE A-6. APPROACH PLATE FOR SALEM

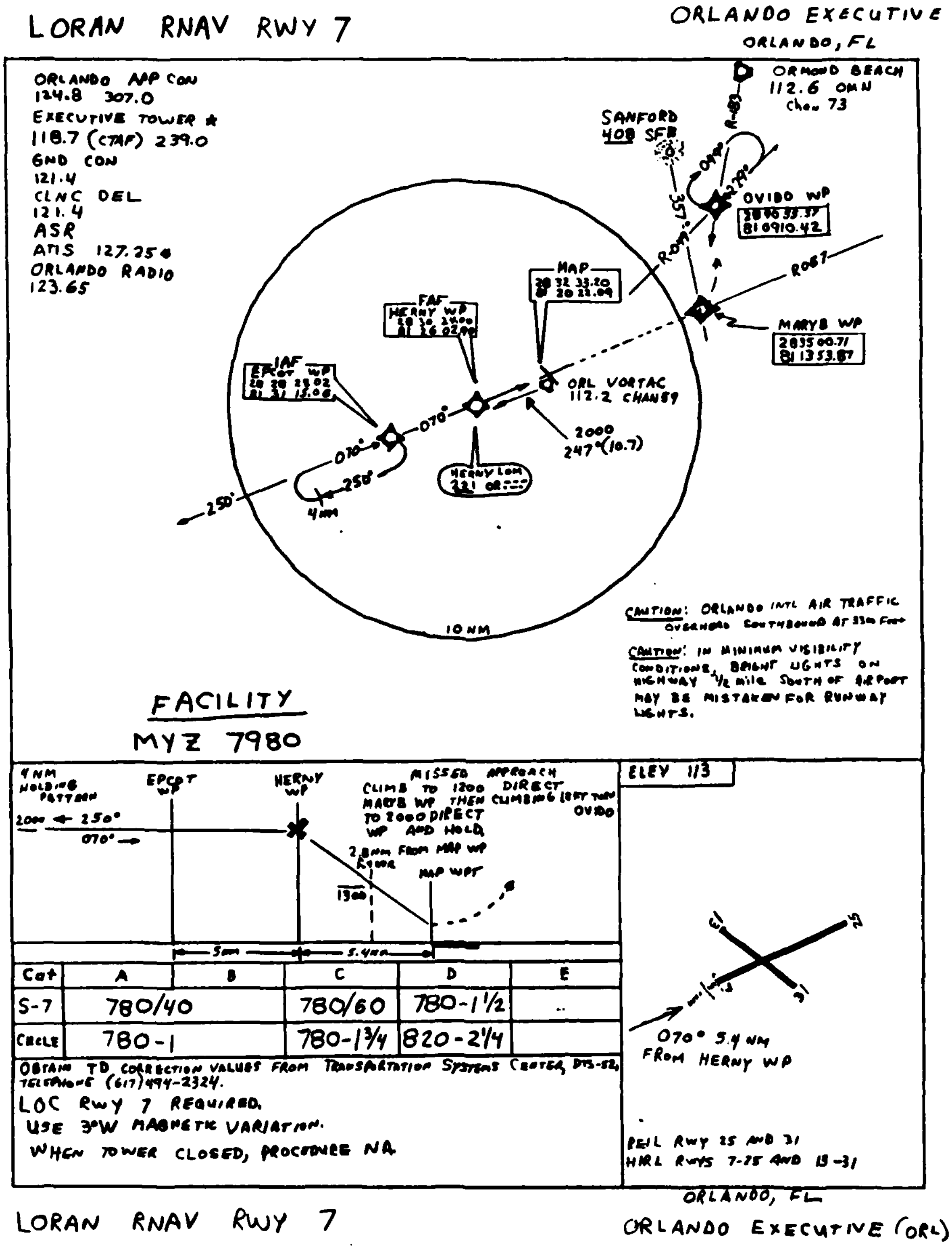
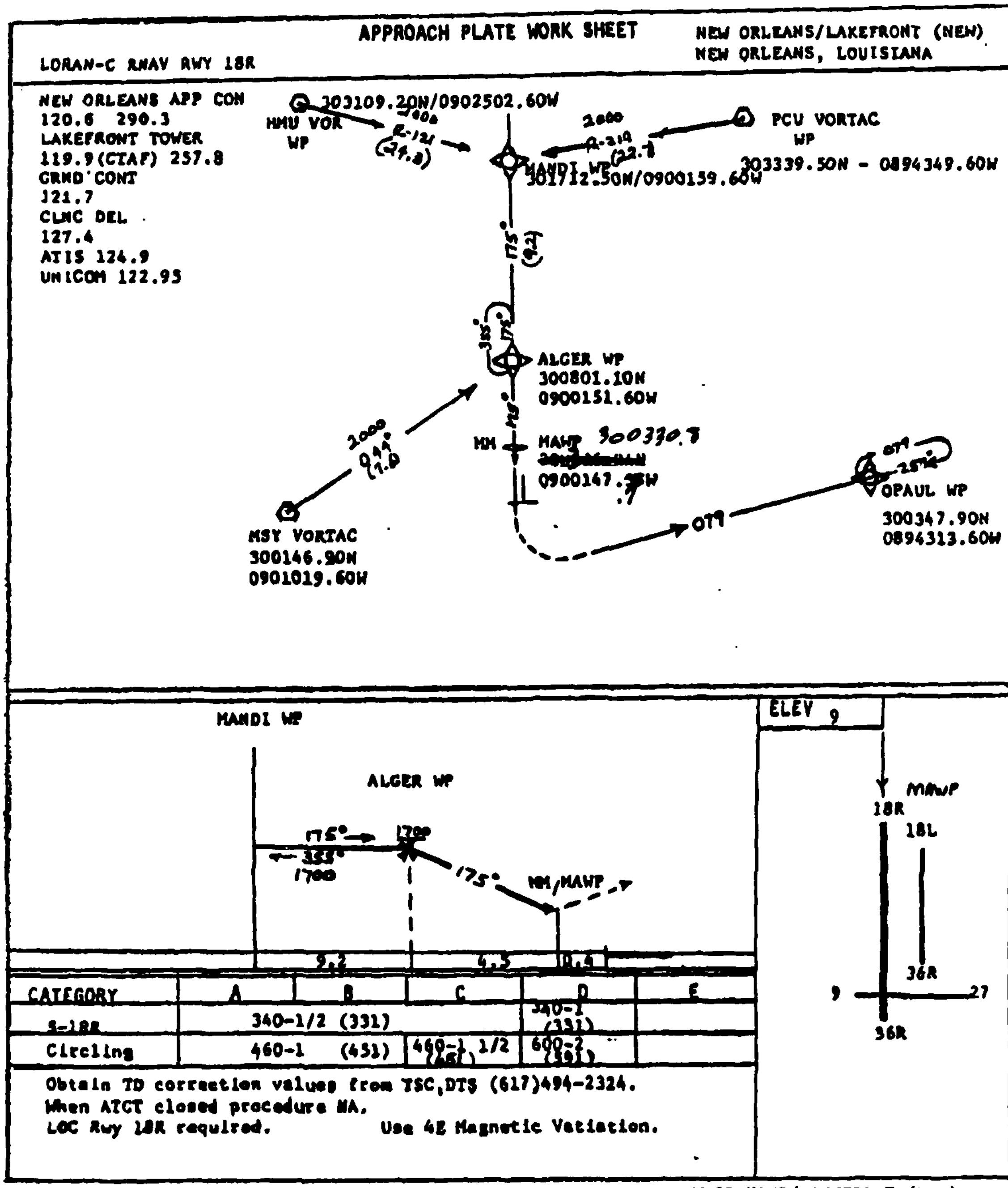


FIGURE A-7. APPROACH PLATE FOR ORLANDO



LORAN-C RNAV RWY 18R

NEW ORLEAND/LAKEFRONT (NEW)
NEW ORLEANS, LOUISIANA

FIGURE A-8. APPROACH PLATE FOR NEW ORLEANS/LAKEFRONT

APPENDIX B

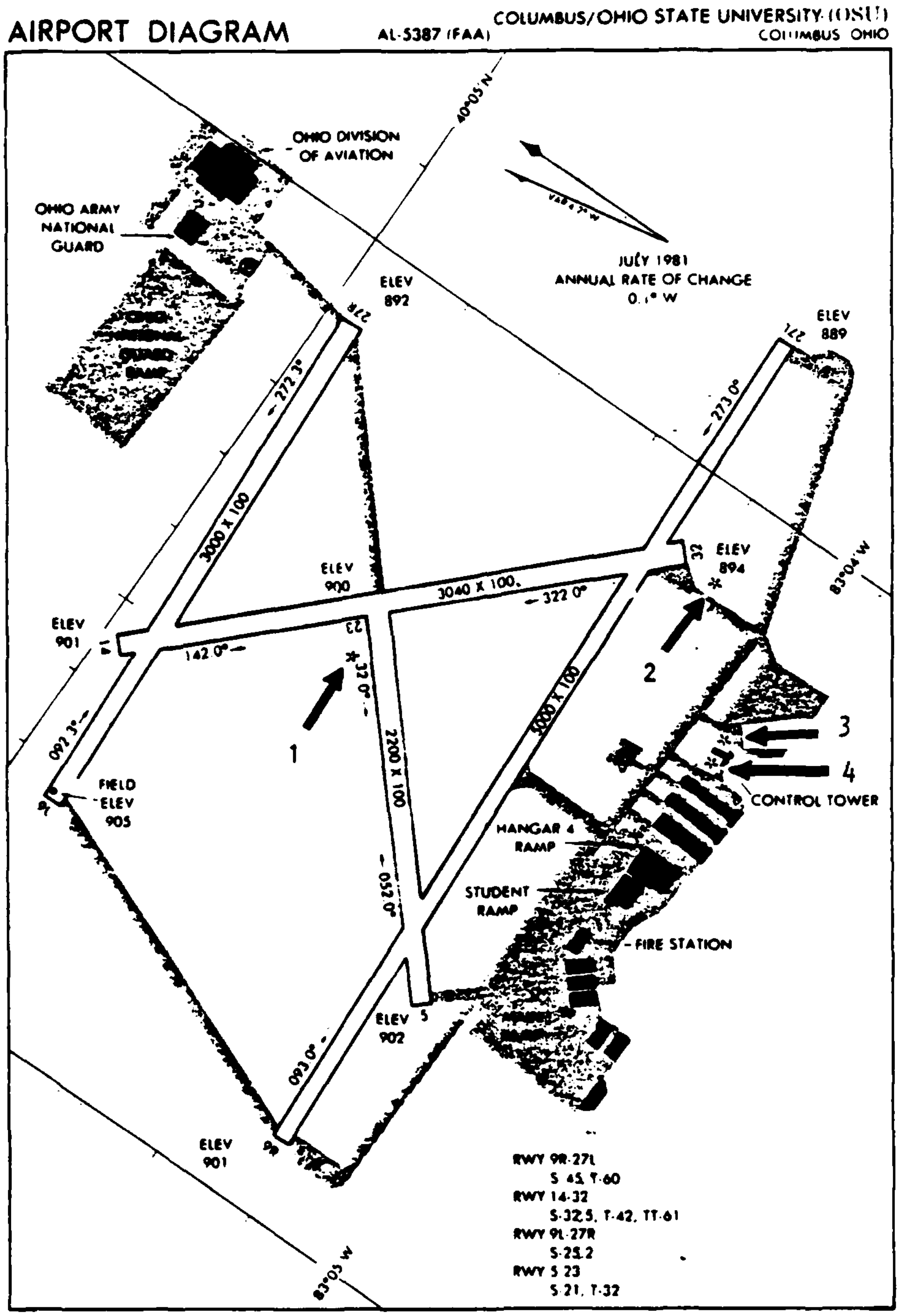
ANALYSIS OF AREA CALIBRATION PROBLEMS AT OHIO STATE UNIVERSITY

In preparing the flight check report for Ohio State University, a large difference between the time differences (TD's) used for area calibration and those recorded by the local area monitor were uncovered. When the area calibration TD values were subtracted from the monitor TD values, a difference of -2.4 microseconds (TDY) and 0.08 microseconds (TDZ) were obtained. Using only the gradient, the 2.4 microsecond shift for TDY should have shifted the Loran C receiver position by at least 1742 feet. Mean ATE and CTE measured during the flight check showed values of -100 and -102 feet, respectively, on the approaches. The two measurements were not in agreement.

Figure B-1 shows an airport diagram for the Columbus/Ohio State University Airport. Point number 1 is the position of the local area Loran C monitor as published for November 1985 and used for area calibration. The position is in the center of the airfield. A phone call to the control tower at Ohio State verified that the local area Loran C monitor and antenna were, in fact, located at the control tower and that the tower location appearing on the airport diagram was correct. The control tower is labeled as point number 3. The navigation equipment errors were small, but both area calibration TD's and monitor position were not correct. One explanation is that the two error sources canceled each other.

If the TD corrections were accurate for the monitor, any error in the published monitor position used for area calibration should have caused an error in the Loran C receiver position. The error should have been equivalent to the distance between the actual position of the monitor (point 3) and the position for area calibration used (point 1). The difference between the two points was 1944 feet north and 604 feet west or 2035 feet at 162°. It was necessary to translate the shift in TD's to a shift in feet to observe the effect on the Loran C receiver position. The gradient and direction of the lines of position were used to convert the shift in TD's to displacement in feet. It can be shown that a TD error of -2.4 microseconds (TDY) and 0.08 microseconds (TDZ) would cause a position shift of 1999 feet at 162° with respect to true North. If the position shift is referenced to point number 1 (the area calibration position), the effective monitor position will be at point number 4. As shown in figure B-1, the effective monitor position (point 4) and the actual position of the monitor (point 3) were very close. Coordinates for the monitor position (control tower) were provided by AVN-230 and were obtained from the airport obstruction chart. Published coordinates of the monitor as of December 1985 are plotted on figure B-1 and appear as point 2. Again, the published value does not agree with the actual location of the monitor.

As described above, the effect of the incorrect area calibration values were the establishment of an effective monitor position very close to the correct monitor position. This accounts for the incorrect area calibration values and small navigation equipment errors.



Label	Position Lat.	Position Long.	Description
1	N 40° 04.80'	W 83° 04.40'	November 1985 Published Monitor Position
2	N 40° 04.58'	W 83° 04.10'	December 1985 Published Monitor Position
3	N 40° 04.48'	W 83° 04.27'	Control Tower per Obstruction Chart
4	N 40° 04.48'	W 83° 04.26'	Effective Monitor Position Resulting from Errors in November 1985 Area Calibration Values (Geodetic and TD)

FIGURE B-1. AIRPORT DIAGRAM WITH MONITOR POSITIONS

END
9-87
DTIC